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DENTAL CARIES

AND ITS CAUSES

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DENTAL CARIES

AND

ITS CAUSES.

AN INVESTIGATION INTO THE INFLUENCE OF FUNGI IN THE DESTRUCTION OF THE TEETH.

BY

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WITH ILLUSTRATIONS.

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PREFACE.

We submit to the English Medical and Dental Professions the translation of a work published simultaneously in Germany and France, which contains the exposition of a theory of the process of Dental Caries. This question bears so much the greater interest as the parasitic theories become more and more the question of the day, and have gained considerable ground within the last few years. They offer, in fact, to Pathology the most satisfactory solutions, and furnish us with the most rational means of combating a number of affections which up to the present day have been ineffectually treated by therapeutic agents.

The theories which are here expounded are founded on research, and on facts so numerous that they are almost beyond any serious question. They have now the sanction of experience and of competent authors and investigators. In Dental Pathology they offer new resources of prophylactic treatment. We therefore believe that in submitting to the profession in England this work, we contribute to the progress of science; and we hope that it will receive the same favour as in Germany and France.

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INQUIRIES

INTO

DENTAL CARIES.

I.

RÉSUMÉ OF THE INQUIRIES MADE, UP TO THE PRESENT DAY, INTO THE NATURE OF DENTAL CARIES.

UNDER the name of Dental Caries is comprehended a pathologic process which, after having more or less softened and destroyed the tissues, occasions a loss of substance, and ends, after the destruction of the pulp, in the entire loss of the dental organ. This process has nothing in common with caries of the bones but the name. It differs from it entirely in its nature. Nevertheless, the name of caries has come into so common use that it would be difficult to replace it by another, and as for the rest, no one will ever confound dental caries with the affection of the bones which passes by the same name.

The nature of dental caries has for ages been the subject of investigation. The ancient physicians, the dentists of their times, who engaged in this inquiry, confined themselves to making hypotheses more or less ingenious, and founded them upon experience and clinical observation. Investigation, in its proper sense, was only possible when the histologic structure of the dental tissues was known.

For a long period two hypotheses held a balanced sway:

one, *chemical*, explained caries by the action of chemical agents, acids in particular; the other, *vital*, considered dental caries as a veritable malady, caused by an organic change, and the reaction of the dental tissues against an external irritation.

The defenders of the chemical theory did not trouble themselves about the vital properties of the dental tissues. Some denied that the developed organs had any such properties; others thought they possessed so little energy that they must always yield under the action of injurious agents, without being able to react in any manner against this irritation.

For them the process followed its course just as though the vital properties had never existed.

These different opinions remain to-day unsolved in spite of the researches which have been made upon this subject. It is true, that in these later days, the chemical theory has seemed to have the upper hand, although quite recently an attempt has been made to reinstate the vitalist theory by the aid of histologic investigations. But by the side of these two hypotheses, other observers, particularly in Germany, assert the parasitic character of caries, attributing it step by step to the action of animal or vegetable parasites.

The results published by these latter authors have not as yet been criticized very vigorously; for, accepted too hastily, in Germany especially, they seem completely ignored in other countries. Messieurs Klencke and Ficinus were among the first to occupy themselves with the histologic alterations of the teeth, and, although their labors have no longer any more than a purely historic interest, we will yet give a short résumé of them.

Ficinus attributed dental caries to a putrefaction produced by the minute infusorial animalcules which live in the mouth and to which he has given the name of *Denticola*. These infusoriæ are found in great numbers in the mucus which covers the teeth, as well as in the carious cavities. They produce, according to him, a kind of putrefaction which, after having first attacked the enamel cuticle, pro-

ceeds to consume the enamel itself and afterwards the dentine. He thinks that the fibres described by Bühlmann, and which are no other than the filaments of the *Leptothrix buccalis*, derive their origin from the infusoriæ which he calls *denticola*, and that the former are formed by contact with the latter.

But this theory does not explain the disappearance of the calcareous salts, which are soluble only in acids, while the process of putrefaction supposes an alkaline reaction.

The investigations of M. Klencke were published a little later. This author adopts several opinions offered by M. Ficinus, but he admits, besides the process of putrefaction, several species of caries.

And first he distinguishes central caries from the common peripheric caries. The former commences in the cavity of the pulp, the latter in the external portions of the teeth.

He also subdivides this latter into three different kinds.

1st. A soft caries, caused by putrefaction.

2d. A soft caries, due to the proliferation of a vegetable parasite called *protococcus dentalis*.

We must remark here that the existence of this epiphyte has not been confirmed by later observers, and that, in spite of all the pains which we have taken in the search for it, we have not been able to find it.

3d. The so-called dry caries, with which the parasites have nothing to do. It is caused by the chemical action of acids upon the dental tissues.

The histologic alterations of which the dental tissues are the seat in caries, were described for the first time with accuracy by Mr. J. Tomes. According to this author, the changes of the enamel are caused, in the majority of cases, by an imperfect development, with a greater porosity of the tissues; a porosity which increases with the progress of the caries.

The canaliculi of the dentine present remarkable alterations during caries. In a cross-section we see them surrounded by a thickish sheath. One might say that the contours of the old cells of the dentine are re-established, and

that the tissue is resolved into its primitive elements of formation. We know, in fact, that the dentine is formed at the expense of cylindrical juxtaposed cells which unite during the ossification of the dentine and become impregnated with calcareous salts. The dental canaliculi alone remain free in the mass with the soft fibrils, discovered by Mr. Tomes, in the very centre of these canaliculi.

In a more advanced stage the elements lose the sharpness of their contours and the entire tissue takes a finely granular aspect. If the destruction is rapid, we find, on the contrary, the canaliculi expanded and with badly defined contours.

The pathologic alteration proceeds along the canaliculi towards the cavity of the pulp, giving, in most cases, to the carious portion of the dentine the form of a brownish cone, with the base turned outwards. In cases where a more extended surface of the enamel has been attacked at once by caries, and where the destruction proceeds rapidly, the cone may exist incompletely, or be entirely wanting.

Around the cone is found a zone relatively transparent, in which the canaliculi contain dental fibrils calcified, which are often separated into portions more or less long, and in some preparations extend beyond the extremities of the canaliculi.

Mr. Tomes attributes this calcification of the canaliculi to an organic reaction of the dentine against the pathologic irritation, and he believes that it retards or arrests the progress of the caries.

Another manifestation of the vital properties of the dentine consists, according to him, in the augmentation of sensibility in this tissue which is observed in some cases of caries. He concludes from this that the dentine is sensitive of itself, and not through its neighborhood to the pulp.

According to Mr. Tomes, acids are the principal cause of dental caries. After having first destroyed the vitality of the parts the acids decompose them little by little. But we do not succeed in producing artificially, by the action of acids upon the dentine, histologic changes like those which we observe in carious teeth. Nevertheless, the decalcification,

the softening, the destruction of the teeth are all phenomena due to the chemical nature of the process. But the dental tissues, while undergoing destruction, react against the action of the destroying agents, and this reaction is made manifest by the calcification of the dentinal fibrils in the parts which surround the carious dentine, and also by increased sensibility.

The observations of Mr. Tomes upon the histologic structure of the dentine have been confirmed and in part completed by a more recent work of M. E. Neumann.* Mr. Neumann endeavors to prove by his observations, which bear almost exclusively upon the caries of the dentine, that this affection has, in part at least, an inflammatory nature. According to this author, the injurious agents irritate the dentine and produce phenomena of organic irritation which end by causing the destruction of the tissue. He distinguishes two series of alterations, viz.: 1st, those of the sheaths of the dental canaliculi and of the intertubular substance, which have the character of simple degeneration, and are found in all cases of caries; 2d, those of the fibrils contained in the canaliculi, produced by an inflammatory process.

The alterations of the first series, identical with those of which Mr. Tomes has given the description, are characterized by a thickening of the walls of the canaliculi. Nevertheless, M. Neumann does not believe, with the English author, that the dentine is formed directly by the calcification of the cells of the dentine. According to him the intertubular substance is formed at the expense of an exudation, and the cells of the dentine furnish only prolongations which are transformed into the fibrils contained in the interior of the canaliculi. According to Mr. Tomes, the thickened walls of the canaliculi are formed by the old cells of the dentine which have acquired new contours. M. Neumann sees in this only a thickening of the normal walls of the canaliculi or dental sheaths, at the expense of the intertubular substance, with consequent obliteration of the canaliculi.

* Sur la nature de la carie dentaire (Archiv. für Klin. Chir., tom. v, fasc. 1, p. 117).

The second series of alterations consists, according to M. Neumann, in a thickening of the dental fibrils in the interior of the canaliculi. These fibrils have considerably increased in diameter and are divided into little bundles slightly separated from each other. He considers them as cells produced by division of the fibrils. If this explanation is correct we should not find in teeth of substitution, whether obtained from man or animals, alterations analogous to those of living teeth. M. Neumann had had occasion to examine a peg of ivory which, inserted into a bone for the purpose of effecting the cure of a pseudarthrosis, had been attacked by the caries of the bone. None of the changes observed in carious teeth were found. M. Neumann concludes from this that experiments made upon substituted teeth would probably lead to the same negative result, and that their caries is essentially different from that of living teeth.

At the beginning of this year (1868) appeared the "Treatise upon Dental Caries" by M. E. Magitot. Some chapters of this work had been published separately the year preceding. The author wishes to prove that the acids contained in the saliva, or mixed with it, are the cause of dental caries, and that the nature of this affection is consequently purely chemical. He has made experiments with the object of artificially producing caries, by the action, during a sufficiently long period, of diluted acids upon teeth. The teeth were, in fact, destroyed, and the author observed curious differences in the action of the various acids upon each of the dental tissues. The teeth destroyed were not submitted to microscopical examination.

The book of M. Magitot contains no new facts upon the subject of the pathologic alterations of the dental tissues. He does not even mention the alterations described by Messrs. Tomes and Neumann, and contents himself with saying that the canaliculi contain sometimes a finely granulated substance.

He attaches great importance to the calcareous deposits in the interior of the canaliculi, and considers them as the result of a secretion from the irritated pulp. While the

enamel is disappearing under the action of acids, the irritation is conveyed across the dentine even to the pulp, which, reacting, throws out a calcareous exudation. This exudation fills the canaliculi from without inwards, towards the cavity of the pulp, and, when they are entirely filled, it is deposited at times on the internal wall of the pulp-cavity under the form of dentine of new formation. The deposition of calcareous salts in the interior of the canaliculi, and the production of true dentine in the pulp-cavity, are, according to M. Magitot, two analogous phenomena.

The portions of the dentine containing these canaliculi obliterated by calcareous deposits, form a cone or zone of transparent substance, which must be destined to arrest or retard the march of the malady M. Magitot does not, therefore, attribute caries exclusively to chemical destruction. He admits at the same time the irritation of the pulp which, by a calcareous exudation, can arrest the destructive progress. The cavity of the pulp once opened, inflammatory symptoms manifest themselves, after which the rest of the tooth, no longer protected by the pulp, undergoes decomposition by the acids.

Before concluding our résumé let us remark upon a strange idea, started a little while ago in England. It would explain not only the destruction but also the formation of the teeth by electricity. This publication, coming from Mr. K. Bridgman, has been indorsed by the Odontological Society of London. The author has demonstrated by his experiments that teeth can be destroyed by electrolysis. But his whole system is based upon a series of hypotheses; he attributes entirely arbitrarily, different electric properties to different parts of the teeth. The pulp vessels should be charged with negative electricity, the normal pulp with positive electricity; but, in a pathologic state, the surface of the dentine as well as the roots would be charged with negative electricity. It is useless to dwell upon this work, inasmuch as no direct proofs are offered of the existence of these positive or negative qualities, nor of the currents which result therefrom.

If we review the numerous and diverse opinions which we have just passed in review, we see that their authors differ in points the most essential. We have said above that the different theories can be ranged in three categories—chemical, vital, and parasitic—which can in their turn be subdivided.

In general, we can say that the chemical process plays an essential part in the production of caries; but it is a question if the organic processes enter equally for a certain share. We shall show in the course of this work, that the organic process is nothing, or nearly so, and that a parasitic element plays an important part in the production of caries, but in a wholly different way from what has been described up to the present time.

II.

ANATOMICAL ALTERATIONS OF THE TEETH DURING CARIES.

Caries, at least in a majority of cases, commences at the surface of the teeth ; it attacks first the enamel, which alone is exposed, while the dentine is covered entirely, either by the enamel itself or by the cementum ; this last is moreover protected by the gums.

Caries rarely attacks the exposed portions of the necks of teeth, and, when it does, naturally has its origin in the cementum. We shall dwell particularly upon the alterations undergone by the enamel and dentine when attacked by caries, as these are the most important tissues of the teeth, and shall speak of its effects upon the cementum only as connected with these tissues.

Of Central Caries.

Many authors, Klencke among others, have asserted the existence of a caries which originates in the interior of the tooth and in the cavity of the pulp. Nowadays most dentists pronounce against the existence of a central caries. It is true that the process of destruction often begins in a minute crevice or furrow in the surface, and so penetrates the dentine even to the pulp-cavity, where it performs its ravages, while the enamel of the surface seems intact, at least to a superficial examination. This caries, although central, has yet its origin at the surface of the tooth. Therefore, in these latter days, the existence of a true central caries has been generally denied.

Although in most cases the caries called central is so only in appearance, there are cases, very rare it is true, where the

destructive process has commenced in the dental pulp itself. In support of this opinion we will cite the following observation, the sole case which has presented itself during the long practice of one of us. Therefore it must be concluded that such cases are extremely rare.

A lady of 21 years of age presented herself and complained of three teeth, one inferior and two superior incisors which had an extraordinary bluish tinge. They were not painful, and one only caused any disagreeable sensation to the patient. She had consulted several dentists, who had told her that her teeth were dead, and there was no remedy. At the surface of these teeth no trace of caries was to be found. The blue color alone met the view and proved their death.

In piercing the posterior face of one of these teeth it was found completely softened, even to the enamel, and the tissues had a brownish color. The root itself was hollowed to a considerable extent. The same was found to be the case with one of the other teeth. The third, whose color was not so marked and which caused no unpleasant sensation, was let alone. As the cause, the patient referred to a blow from a fall which she had had in childhood, and which was followed by a swelling of the face. The pierced teeth were filled with gold. As for the inferior, there subsequently developed an abscess which was treated by puncturing the root.

It follows, from these observations, that the vessels and nerves of the pulp had been lacerated at the time of the fall of the patient, which lesion was followed by the death of the pulp. But this might have taken place without the destruction of the dentine following. We cannot explain in this case the cause of the destruction of the dentine, for the teeth could not be examined by the microscope. Facts of this kind must never be confounded with those of ordinary dental caries, which is due essentially to the action of destructive agencies acting from the exterior.

We believe then that there exist cases where the dental tissues are attacked and destroyed from the cavity of the pulp; but these cases are extremely rare, and the conditions of their

production are not yet well understood, except perhaps the previously necessary death of the tooth.

Caries of the Enamel.

Since caries begins ordinarily at the crown of the teeth, the caries of the enamel constitutes the first stage of the process. The destruction reaches the dentine later, but the first pathological phenomena make their appearance in it, even before the enamel is destroyed in its whole thickness. Most frequently there is seen a black or brownish point in one of the furrows or folds of the crown. On examining a section of the diseased portion the dark color is seen to have its seat in the superficial layers of the enamel, and penetrates clear to the bottom of the furrow, where the thickness of the enamel is, in general, less than at other points.

If, on the contrary, the caries begins on a smooth surface, the approximal face of the tooth, for example, there appears an opaque spot of a yellowish or brownish shade. The points where anomalies of form, of thickness, of quality of dentine exist, are the preferred seats of caries. The dark color of the spots increases with the progress of the disease; sometimes the centre is of a dark brown while the periphery has a yellowish or whitish tinge. The harder the enamel the darker is the color, for in a dense enamel the progress of the caries is slower and the intensity of the color increases more rapidly than the process, which is a long time in extending itself to the periphery, and to any depth.

The carious spots are easily distinguished, for in them the enamel has utterly lost its normal appearance; it is transformed into a chalky mass, analogous to that which forms the congenital white spots of the enamel, which are also a frequent seat of dental caries. At the carious points the enamel also possesses less hardness than in the normal condition; but it is sometimes so resistant that it is almost impossible to detach fragments at the surface. Often the superficial seats seem to offer greater resistance than those which are deeper, which, the former once removed, permit themselves to be more easily excavated.

In other cases the consistency of the enamel is much feebler; it is no more than a chalky mass, or even of no greater consistency than paper-pulp. These differences are explained partly by the stage of destruction, the density of the enamel diminishing with its progress; but the pre-existing differences of the chemical composition, or consistency of the tooth, take an equal part, for the enamel is softened much more rapidly in some teeth than in others. At the beginning, the surface of the enamel is smooth and uniform; the fine and parallel striæ which are ordinarily noticed on its surface, are well defined; there is, as yet, no loss of substance. This stage, in which the alterations may reach even to a considerable depth in the dentine, is generally described under the name of *dry caries*. The more the tooth resists the longer is the duration of this stage; but, in many cases, this stage has but a short life, and the disease rapidly passes on to the *humid* form.

Soon the portions of the enamel transformed by the caries are destroyed; there is a loss of substance sometimes spread over the surface, or forming a carious cavity, but, generally, this destruction has little extent before the dentine has been attacked in its turn. In this latter case the caries progresses rapidly, and extends itself in depth and laterally. The portions of the enamel situated at the borders of the cavity are undermined at their base, or greatly softened on their internal surface, and break in because they have no longer the natural support, the dentine.

We may distinguish two forms in the destruction of the enamel; one *progressive*, extending itself over the surface, the other *penetrating*. The former shows itself especially in cases where the caries has attacked a smooth surface of the enamel, the latter is found where the caries has commenced in a furrow. In the former case the caries has attacked, at the beginning, a considerable part of the surface, and the destruction will be quite extensive before it has penetrated as far as the dentine. In the latter case, on the contrary, the alteration of the enamel is limited by the sides of the furrow. The enamel is generally thin at this point, so that

the dentine rapidly becomes exposed, and its quick destruction causes the phenomena of the caries of the enamel to pass to the second form.

When a carious cavity is formed in the enamel, it is not unusual to see this tissue become carious, sooner or later in one or several other points; these new points of disease progress by themselves, or add their forces to those already in existence. It is more rare to see the caries spread itself at once over a large surface; there are, nevertheless, cases where the greater part of the enamel is attacked or destroyed by caries, and, at the same time, one or several carious cavities formed. In such cases there are generally faults of formation of the enamel, which presents, at several points, depressions, hollows, &c., or anomalies of structure. Each one of these points may then originate, either simultaneously or successively, the production of caries.

Histologic Changes in Caries of the Enamel.

Great importance has generally been attributed to the enamel cuticle, discovered by Nasmyth, in the production of caries, some regarding it as a protecting covering, others as the seat of the disease.

The cuticle of the enamel is, as is known, a very thin membrane, whose existence is easily shown by immersing a tooth for a short time in a weak solution of hydrochloric acid. We can thus readily detach the cuticle from the tooth's surface. This membrane, according to the investigations of M. Waldeyer, must be the vestige of the first formative strata of the enamel, and particularly of the intermediate layer and the external epithelium. After the development of the enamel has been completed the elements of these strata are transformed into a pavement-epithelium composed of two or three layers of large polygonal cells, which cover the surface of the enamel. These cells become smooth, little by little, till their nuclei are difficult to be seen; and, during the dental evolution, they unite into a membrane of homogeneous appearance, in which is to be

seen neither nucleus nor cell, and in which Mr. Waldeyer, by means of a solution of silver, has been able to render again visible the cell contours.

It is generally thought that the cuticle, on account of its great resistance to chemical agents, must protect the teeth. In fact, according to Ficinus, neither maceration nor boiling in water affected it, and concentrated mineral acids did not dissolve it. Potassa and soda gave it a whitish appearance, and caused it to swell, but without making it lose its consistency. But it must be remembered that if this membrane cannot be attacked by acids, it permits itself to be penetrated by diffusion; we must not then lay too much stress upon its *rôle* of protection. If the acids can reach the enamel by passing through it, as the method for the isolation of the membrane has already proved, it can at the most retard their action, but cannot hinder it completely. It may then be useful in cases where the acids act only in a transitory manner; as, for example, when they have been introduced into the mouth with the food, or where they have come from the stomach, as happens in certain diseases, and are immediately removed from the mouth. But if a continuous acid reaction takes place in the mouth, as happens in the case of fermentation, then the protective office of the cuticle is *nil.*

In many cases we cannot even invoke the protective office of the cuticle, for it is often worn away on the masticating surface of the teeth, and may be wanting entirely to a greater or less extent. This cuticle is frequently wanting in the furrows or chinks of the masticating surface, which are also the favorite seats of caries. It has been deduced from this fact that caries is developed on account of the absence of the cuticle, but this chosen seat is explained as well by the presence of the furrows which favor the development of fermentations and chemical decompositions.

It is astonishing to see authors defending the protective *rôle* of the cuticle, and at the same time admitting that it is the seat, the abiding-place of caries. Messrs. Ficinus and Klencke share this opinion. They admit with Erdl, that at

the beginning of caries, the cuticle, at the surface of the brown spots, is covered with a deposit whose nature they do not agree upon. Ficinus says this deposit is formed of vibrios, and of the fibres called by Bühlmann filaments of the *leptothrix*. According to Klencke it consists of these elements sometimes, but, in other cases, there are found the cells of his pretended *protococcus dentalis*.

It is in fact easy to show that, at the point of the carious spots, the cuticle is almost always covered with the accumulated deposits of *leptothrix buccalis;* there is found there a substance finely granular, or bed of fungi, which is composed of very minute sporules. At the surface of this granular substance there are also to be found at times very delicate filaments which spring from it, and which are identical with the fibres of Bühlmann. As this fungus* plays a very important part in the production of caries, we will proceed to study it more in detail.

Leptothrix Buccalis.

There is almost always found in the mucus of the mouth, at the surface of the tongue, and in the interstices of the teeth, a whitish, cheesy substance, formed in great part by the *leptothrix buccalis*. Under the microscope we see a gray, finely granular mass, gangue or matrix, then filaments delicate and stiff, of various lengths, which erect themselves above the surface of this granular substance, so as to resemble an uneven turf. It is in the interstices of the teeth that this fungus attains its greatest size, when we do nothing to check its development; its filaments there attain considerable length, and form bundles, sometimes parallel and undu-

* It may astonish some to see us designate the *leptothrix buccalis* by the name of fungus, and not by that of alga. Opinions are divided on this question which, for the rest, seems to have no great importance for our subject. We have simply used the name most common in Germany, without permitting ourselves to judge a question purely botanic. Yet, if it should come to be shown that the opinion of M. Hallier is correct, which is that the *leptothrix* is only a form of development of the fungus *penicillium glaucum*, it must be admitted as without doubt that the *leptothrix* is a fungus.

lous, at others firmly interlaced among one another. On the surface of the tongue we see cylindrical or club-shaped elements, which are epithelial prolongations of the filiform papillæ of the tongue, as Kölliker has proved.

These prolongations are covered by a rather thick mass of granular substance of *leptothrix*, bristling at times with short filaments. In the fluids of the mouth, detached filaments are often met. The epithelial cells of the mouth are also frequently covered with numerous fine, oblong granulations, identical with those which compose the bed of the fungus. If we closely examine the grayish masses which the granulations form at the surface of the filiform papillæ, we see that they are composed of epithelial cells, detached in part, and dissociated, covered with thick masses of granulations which unite and make of them a compact mass. The club-shaped prolongations which result have often very well-marked contours, and the granulations are so intimately interwoven that the substance often appears homogeneous, but the addition of a little acidulated liquid permits the granular elements to be readily isolated. The cheesy matter which collects in the interstices of the teeth has an analogous structure, except that the granulations, instead of attaching themselves to the epithelial cells, are joined to the filaments of the fungus, cover and unite them.

It is easy to follow the formation of this substance. We observe, under the microscope, filaments upon which granulations have fixed themselves; some enveloped by a sheath of granulations, some united and intermingled with them. Frequently a great portion of the cheesy substance is exclusively composed of the granulations, fine, and generally a little drawn out, of which we have spoken.

These granulations are, according to M. Hallier,* only movable spores in repose, which wander during a certain period in the liquid, but finally attach themselves somewhere and increase by forming new articulations. If these observations are exact, as we are inclined to think, the

* Die pflanzlichen Parasiten des menschlichen Kœrpers. Leipzig, 1866, p. 66.

movable spores resemble vibrios which are found in the mucus of the mouth, and possess the power of rapid movement. These organisms, called *denticolæ* by M. Ficinus, belong then not to the animal but rather to the vegetable kingdom. Moreover, M. Ficinus compared them with the so called filaments of Bühlmann, or filaments of *leptothrix*. He had seen spores, which he considered infusoria, move for a time in the liquid among the filaments of the *leptothrix* and epithelial cells, and afterwards attach and fasten themselves to one of the filaments. Soon others were added, and thus was explained the formation of the filaments and epithelial cells covered with granulations of which we have just spoken M. Ficinus also believes that the filaments are due to the juxtaposition of the granulations, which is not correct. It appears, on the contrary, that the granulations push out prolongations, and that thus is formed successively an articulated chain. As M. Ficinus took the *denticolæ* for infusoria, he could not have had a just idea of the nature of the fibres of Bühlmann. Later the vegetable nature of the filaments was recognized, but that of the granular substance could not be explained. M. Robin among others thought it was formed by the débris of alimentary substances. This supposition is false; for, if this were so, the granular substance would not always present the same characteristic aspect. Composed, in fact, of granulations, fine, elongated, and shining, it has a peculiar matted appearance, by which it is easily recognizable.

According to M. Hallier, to whom we owe the opinions just given upon the spores of *leptothrix*, this fungus may be only a form of development of the *penicillium glaucum*. If so this fungus should always be produced when the spores of *penicillium* are kept in a watery liquid. We have not verified the truth of this opinion. However this may be, M. Hallier explains by his theory the formation of the granular substance, and teaches us the nature of the *denticolæ* of M. Ficinus.

It remains to explain why, in the mouth, the spores so quickly lose their movements; in the cheesy substance,

where the granulations are found closely packed, no movements are perceived. A portion of the elements which move about in the saliva as vibrios are larger than the little granulations of the *leptothrix*, which can nevertheless change both form and volume.

In cultivating the *leptothrix* in the saliva with the addition of sugar, or any other appropriate liquid, we ordinarily see developed movable spores in numberless quantities, and endowed with a power of very rapid motion. If the movements cease, which is observed on the edges of the preparation where it begins to dry, the spores resemble exactly the granular masses of the *leptothrix* which are met with in the mouth. The cessation of movement in the mouth can be explained by the viscosity of the medium, and by the presence of the buccal mucus.*

We have already observed that it is always very easy to recognize the elements of the *leptothrix* by their characteristic aspect; but it is always desirable to have at hand a chemical reagent which will enable us to perceive the existence of the fungus when its external aspect is deceptive. This reagent we have found in iodine and the acids, which give to the

* The details which we have just given explain equally well the various opinions which have been expressed upon the composition of the tartar of the teeth, and upon the inferior orders of being which it contains. According to M. Mandl, the tartar may be composed of the calcareous carapaces of infusoria which live by millions in the mucus of the mouth. M. Ficinus had the same opinion, as his *denticolæ* are evidently the equivalent of the *infusoria* of M. Mandl. Formerly the tartar was regarded as a deposit of salts dissolved in the saliva; its chemical composition, analogous to that of the inorganic products of the salivary liquids, still pleads in favor of this opinion. M. Robin found in the tartar filaments of *leptothrix*, and doubted the indications of M. Mandl. According to our researches there do exist in the tartar filaments and granulations of *leptothrix*. They are easily recognized after treating the tartar with diluted acids. It is probable that it may contain at times more filaments, at others more granulations of *leptothrix*, so that there may occur cases where there can be found only granular masses, which would very closely resemble the indications of M. Mandl. The infusoria with calcareous shells must be rejected. As for the salts of the tartar, they are precipitated very probably in the saliva, mixed with viscous mucus which incloses the filaments of *leptothrix*, and deposited gradually upon the surface of the teeth.

elements of *leptothrix* a beautiful violet tinge. We obtained this reaction in trying the effect of that for cellulose (colored blue by iodine and sulphuric acid) upon our fungus, and we have noticed that MM. Leyden and Jaffé had already recommended the same reagent for the *leptothrix* which is found in putrid sputa, and in the lungs.* They are treating of fungi which are discovered in sputa which have become putrid in cases of gangrene of the lungs. The sputa had a very acid reaction. The fungi were colored a beautiful violet by the simple addition of iodine. The fungi of the mouth which have undergone no change are colored, for the most part, yellow by iodine; generally we notice a violet color only after adding an acid. Sometimes we obtain a violet reaction by the aid of iodine alone, a fact which we must attribute to acidity of the buccal mucus. It is not necessary to make use of sulphuric acid, as in the case of the reaction of cellulose; but any acid whose action is not too violent will render the same service. We have obtained excellent effects by the use of weak hydrochloric acid, by acetic, and by lactic acid. Sulphuric acid has with us less generally succeeded, because it occasions so rapidly other decompositions. The reaction which we have obtained is identical with that which MM. Leyden and Jaffé have described, for the color is likewise that of a beautiful violet (not blue as in the action with cellulose), and it is the contents of the filaments and not their envelope which is colored. We know this by the circumstance that the *septa* of the filaments remain inaccessible to all coloration. It results from this that the presence of an acid is indispensable to obtain the reaction. Nevertheless it will be useless to have recourse to any acid when the liquid which contains these fungi is acid enough, as is the case in putrid sputa, and even, at times, in the mucus of the mouth.

We almost always find, as we have already observed, at the surface of the carious points of the enamel, a coating of

* *Vide* Leyden and Jaffé. Sur les crachats putrides, la gangrene pulmonaire et la bronchite putride. (Archives allemandes de clinique medicale. Tomes ii, iv, and v, 1866, p. 488.)

leptothrix, even when this surface seems still polished and intact. This coating adheres strongly, and is not so easily removed as the cheesy masses of *leptothrix* which cover other parts of the surface. When, by the aid of a weak acid, the enamel cuticle is removed, we find this coating thickened, composed most frequently of the accumulations of granular matters, and there is rarely to be recognized the presence of filaments of *leptothrix*. The fungi seem to have penetrated through the enamel cuticle, as they adhere to it strongly; but, at this stage, it is not possible to prove their presence in the enamel itself.

The filamentous and granular matters of *leptothrix* which are found accumulated on the cuticle of the tooth are not arranged in any regular manner; we often see them under the form of rounded and irregularly disposed masses. Neither are these masses well defined, but are joined one to another by delicate beds of granular matter. It is probable that these appearances have formed the base of the observations of MM. Erdl, Ficinus, and Klencke; but they have not given us exact descriptions of them. We have never been able to perceive the presence of the cells described and pictured by M. Klencke in his *Protococcus dentalis*, and we think, after investigations made upon a great number of teeth which have all yielded us identical results, that his conclusions are founded in error. We are the more convinced of the correctness of our own results, in that no observer has succeeded in confirming the facts as stated by M. Klencke. Yet it is hard to say what could have given rise to this error, inasmuch as there exists absolutely nothing which offers any analogy to the facts as stated. M. Klencke describes cells of from $\frac{1}{150}$ to $\frac{1}{200}'''$ in diameter, which would be collected, at the beginning of the caries, in simple beds crowded together upon the enamel cuticle, and, later, these same cells would form layers superposed, and capable of multiplying by division or by endogenous proliferation. The mode of propagation of these cells penetrating the dental substance is described and pictured with so great exactness that we

may be permitted to wait, at least until the discovery again of some analogous elements.

We find, occasionally, after having removed, by the aid of a weak acid, the cuticle which covers the tooth, minute elements, crowded against each other upon the denuded surface, which might be confounded with a sort of granular epithelium with ill-defined contours. These are nothing but the extremities of the enamel prisms left adhering to the cuticle. It is impossible to confound them with the cells of the fungus. It might with equal probability be supposed that such an error could spring from portions of vegetable or other alimentary substances which are found adhering to the teeth. It seems to us, from certain indications, that the round, granular masses of *leptothrix* which form upon the surface of the cuticle have given rise to this error, although a certain power of imagination is necessary to consider these irregular and badly defined masses as cells. In caries of the enamel these fungi, as we shall show, appear not to play a part as important as in that of the dentine. The action of acids and the decomposition of organic substances, which is its consequence, and which is recognized by a brown color, seem to us to demand more attention. Yet equal account should be made of the effect produced by the fungi.

The seat of *leptothrix* seems generally to be confined to the surface of the tooth as long as the dental substance remains intact. It may be otherwise when the teeth are covered with a greenish coating, and the lesion seems to have its seat in the very substance of the enamel.

We meet with this greenish coating in young people and upon the front teeth. It is generally attributed to the alteration of the enamel cuticle. The action is not bounded by the surface of the tooth, but penetrates even into the substance of the enamel. We have examined but a single case of this kind. We removed from the surface of the tooth small green and rather hard portions which resembled tartar, but which appeared to be rather minute fragments of enamel. Nevertheless it was impossible, after examining them under the microscope, to decide whether it was enamel

or not. After having dissolved out the calcareous portions, we were convinced that the whole substance was strewn with granular matter of *leptothrix*. The greenish tinge was found only at the surface of the pieces; the acids could not destroy it; it had an appearance of shreds, delicate and plicated, or perhaps granular, and without other structure. It is important, therefore, to make new experiments to ascertain if, at the place of this green color, the fungi penetrate the substance of the enamel, or if we must attribute it to a particular kind of tartar, as appears much less probable. If the first supposition should be confirmed, we must seek to find why and how the fungi succeed in penetrating the enamel. It will not be less interesting to know the origin and the cause of this greenish color.

As regards the elements of the enamel, no particular change seems to precede its alteration. It can only be shown by the aid of the microscope that it is easier to recognize in minute fragments of diseased enamel the structure of this tissue, than in its fragments in a state of health, when the union of the prisms can with difficulty be perceived. This phenomenon can be explained by the disappearance of the calcareous salts consequent upon the work of caries. Carious enamel appears under the microscope like that which has been submitted to the action of acids, and differs only by a little more or less brownish color. The farther the work of caries has proceeded, the easier it is to prove this difference. There are found in minute cavities of the enamel delicate débris of this tissue. The extremities of the enamel prisms and their oblique striæ have contours so fine that it is only by the shade of brown that we can recognize them. This occurs likewise when we employ acids. We find no more than a residue, very delicate and of a membranous nature, which reveals the composition of the enamel, whose total destruction is not slow in taking place.

The porosity of the carious enamel, which makes this tissue lose its normal transparency and its hardness, is the same as in enamel exposed to weak acids. It is quite easy to detach from it portions which, under a moderate pressure,

are reduced to minute débris. By these processes the enamel prisms separate only exceptionally; the fragments have, for the most part, a direction inclined and oblique, and the isolated prisms appear only under the form of very short fragments. The porosity cannot then be attributed to a diminution of cohesion between the enamel prisms, but we may admit, as very probable, that fissures or meshes of a very great delicacy traverse the enamel in directions the most varied, and completely independent of its histological composition. The porosity is equally due to the action of acids. It is produced by the dissolution of the calcareous salts, and perhaps by the production of carbonic acid, which may cause the dissociation of the smaller particles of the enamel. The brownish color of carious enamel, which exists also in carious dentine, arises probably from the change of the organic portion of these tissues. In no case is this color caused by the *leptothrix*, which remains colorless, or causes a slightly yellowish shade only when in beds of great thickness. In a good number of cases, and notably in carious cavities, the *leptothrix* appears to produce a yellow color, but, on attentively examining, we shall be convinced that this color proceeds from the surrounding diseased materials. We can, on the other hand, in microscopic preparations, easily distinguish by their brown color the residues of dental tissues, which are covered with masses of *leptothrix*, while the *leptothrix* alone will have a grayish appearance. The color will vary in intensity, as we have already shown, and, in general, it will be dark in proportion to the hardness of the tooth, the age of the caries, and the time the color has had to develop itself. When the enamel has not yet undergone decomposition, we ordinarily observe this color only upon the upper layers, without doubt because the cuticle contains a greater proportion of organic elements subject to change. We might think that this was caused also by the easy access of the air to the parts; nevertheless, and contrary to this opinion, we can say that this color is formed anew in the dentine after having disappeared from the deeper parts of the enamel, and that it gradually lessens as it extends to the

cavity of the dental pulp (Plate I, Fig. 2), where, upon a point of the left side of the crown, the brown color of the enamel diminishes little by little from the surface to the deep parts, and becomes again more intense at the surface of the dentine.

When the caries has occasioned a loss of substance at the surface of the enamel, the bottom of the cavity is always covered by the granular masses, and by filaments of *leptothrix*, which penetrate the inequalities and excavations of the surface. The minute cavities frequently found in the depths of the enamel are filled with *leptothrix*, and with débris of enamel mixed with it. It is in general very difficult to recognize by the aid of the microscope the elements of the enamel when they have become greatly softened. Yet, in cases where the oblique striation is well pronounced, we sometimes find fragments of enamel colored brown, and almost entirely deprived of calcareous matters. Masses of *leptothrix* envelop them, and contribute, by their prodigious proliferation, to their destruction.

In our opinion the progress of caries of the enamel is this: By the action of an acid the enamel becomes porous at some point, and loses its normal consistence. At the same time there is seen to appear a brown color, in consequence of the change which has taken place in its organic structure. There is formed at the surface a bed of *leptothrix*, which probably penetrates the dental cuticle, if it still exists, and destroys it. Chinks and fissures are opened in the enamel, which has become less consistent. Acid liquids and granulations of *leptothrix* penetrate there, while minute fragments become detached, and are promptly enveloped by the elements of *leptothrix*, which, joined to the continued action of the acids, hasten the dissolution. There are many cases where the work may be stationary for a long time, and perhaps for always, corresponding to that of the caries called dry, characterized only by the brown color of the surface, and a little more porosity, which should be attributed to the more decided action of acids. In answer to what we have just said may be cited the alterations of the enamel which appear almost

immediately after the commencement of the diseased action, when the brown color has hardly had time to become formed. We can attribute these differences in the progress of the disease only to particular predispositions, due, it may be, to vicious structure, or to differing consistency, or resistance of the enamel.

Caries of the Dentine.

In the dentine the work of caries begins generally as soon as that of the enamel has pentrated to its surface. Particular circumstances enable us to ascertain whether any alteration, properly so called, and loss of substance at the surface of the enamel, have or have not preceded this morbid action. We can also divide into two periods the action of caries in the dentine, viz., *that of the preparatory work of the caries, and the period of destruction.* Before decaying the dentine also undergoes certain transformations which can be recognized, as in the alterations of the enamel, by a brownish color more or less marked, and by a lessening of consistency, due to the loss of a portion of the calcareous salts. We observe, moreover, when the disease has progressed to a certain degree, certain histologic changes which were thought to be the result of an active, vital action, and which can only be attributed to the proliferation of the *leptothrix.*

These same vegetations play also a very important part in the definitive alteration which takes place in caries of the dentine. The caries ordinarily proceeds from the enamel to the dentine; more rarely it has its point of departure in the cement, when this has become exposed, or is defective. Caries may also commence directly in the dentine when it is denuded, whether by a vice of conformation, or by an external lesion. The march of caries is still more rapid in the dentine than in the enamel. Starting from a minute point upon the surface, the caries may promptly extend through a great part of the dentine; that of the enamel cannot make such rapid progress. The more rapid march of the caries in the dentine is occasioned by its structure. The minute dentinal

canaliculi, so accessible to liquids, offer to the action of destructive agents a much more extended surface, and permit them to penetrate to the depths of the dentine, an action not possible in the enamel which has not these canals.

Another cause, which, in the majority of cases, explains the more rapid march of caries of the dentine, is this, viz., the carious cavity once formed, the destructive process can develop itself freely without hindrance from the friction of the teeth during mastication, or from the cleansing of the mouth. While at the surface of the teeth the injurious substances are continually removed, and the enamel forms upon the borders of the cavity a protecting wall, favorable to the development of caries behind it. Its canaliculous structure appears, however, to be the main cause of the more rapid progress of caries in the dentine, and the observation of the facts leaves no doubt upon this subject. *The caries follows chiefly the direction of the dentinal canaliculi*, and extends itself less easily and with less rapidity in the direction of the width of the tooth than in that of its depth, that is to say, towards the cavity of the pulp.

If we divide a carious tooth in the direction of its length, we find, as Tomes has first remarked, that the dentine altered by caries, when no destruction has as yet taken place, presents the form of a cone with its base turned outwards, and of a brownish color, which owes its origin to that which the caries follows in its progressive march, viz., the direction of the canals towards the pulp; the conical form is determined by the convergent direction of the dentinal canaliculi. (Plate I, Figs. 1 and 2, shows, three times magnified, cones of dental caries upon a tooth divided lengthwise, with and without alteration at the surface.)

When a portion of the dentine has been destroyed by caries, it can no longer have the form of a perfect cone; but there is always found, at the circumference of the carious cavity, a zone of altered substance which goes on diminishing in thickness in the direction of the pulp. We find these cones in teeth altered by caries at a period when the exterior surface of the enamel has still all its polish, and, consequently,

has lost no part of its substance.* But, at this epoch, the whole thickness of the enamel is already changed, and there exists no covering of normal enamel at the surface of the dentine. M. Magitot says that the cone commences sometimes at a point at a distance from the surface of the tooth. We believe that the tooth pictured by this author can be explained by supposing that the section, in the direction of its length, has not been made across the centre of the caries, and, consequently, has not touched the point whence the morbid action has been propagated from the enamel to the dentine. The alterations effected by the caries in the dentine may have extended themselves laterally to a slight depth, and have left untouched the more superficial portions. When we have made sections of teeth across the centre of the caries, we have constantly observed that the alteration had its beginning at the surface of the dentine. The cones which we have mentioned have also been spoken of and described by various authors, and especially by MM. Tomes and Magitot. Nevertheless we have reason for surprise that these cones have not been considered as the point of departure of the caries itself, but rather as the result of an organic reaction which preceded the caries, and opposed itself as much as possible to its progress. After our experiments made upon a great number of teeth cut across in every direction, we cannot share this opinion. We think, as does also Mr. Spence Bate,† the cones are only the first degree of the work of caries in the dentine. This results from their physical properties; the color is brownish; the consistence lessened; and the transparency greater.

We have found the *brownish color* in all the cones, whether there has or not been loss of substance at the surface of the tooth. In speaking of the enamel, we have already expressed the opinion that the brownish color is due to a decomposition of the organic portions of the tooth. The intensity of this color differs in the dentine as in the enamel. It is darker as

* Traité de la carie dentaire, 8, 26.

† Report of the Sittings of the Odontologic Society of London. March 7, 1864. Brit. Journal of Dental Science.

the progress of the caries is slower and the density of the tooth greater. As a general rule we may say that the color is diffused; from time to time we find in the dental canaliculi minute granulations of pigment which are deposited there in greater or less quantity. *The hardness of the substance which has acquired the conical form* also varies greatly. When there has not yet occurred any destruction of substance, nor any carious cavity, this hardness may, in certain circumstances, be quite marked, above all in the deeper seats, and in teeth which are naturally very hard, and consequently in the cases of caries called dry. Notwithstanding, it is easy to convince oneself that, even in this form of caries, the consistence of the cone, however hard it may be, is always less than that of the sound portion of the same tooth. In other cases, on the contrary, all the substance which constitutes the cone is manifestly more softened than the dentine in its normal state. It is to be remarked that the deeper seats of the disease are always less softened than those at the surface. This is markedly the case when the caries has hollowed out a cavity. We find then, among the most superficial layers, always a softened layer of dentine which is on the way to complete dissolution. The thickness of this layer varies greatly; in moist caries it is quite thick, and insensibly extends itself to the deeper parts of the cone.

In the drier caries, the softened layer of the surface has a much less thickness, and at times is wanting altogether. These differences evidently depend upon the rapidity of the evolution of the caries of the dentine. If the pathologic alteration of the dentine which has preceded its decomposition has occasioned a considerable softening of the substance, the caries will naturally make more rapid strides, and a thick layer of substance undergoing decomposition is upon the point of detaching itself at the surface. But, if the dentine is very hard and little softened by the work of the caries, the decomposition extends itself but slowly, and the destroyed substance at the surface forms but a thin layer, and sometimes seems not to exist at all.

The transparent appearance of the conical substance equally

proves that it is the commencement of the work of caries. It is especially easy to recognize it in thin portions which are detached without difficulty from the softened carious substance; or, if this is too hard, we can always perceive it in sections rubbed down with pumice. The brownish color is scarcely seen in such thin preparations; we see it well only when it is very intense; therefore MM. Tomes and Magitot have not attached a sufficient importance to it.

The dentine, as regards transparency, has properties the very opposite of those of the enamel. While the enamel is translucent in its normal state, the dentine presents an opaque whitish or yellowish shade; the enamel loses its translucence by caries, while the dentine becomes more translucent and almost cartilaginous. We have already remarked, in treating of caries of the enamel, that we must attribute its loss of transparency to the action of acids. We shall take occasion to show further on that acids produce the same effect out of the mouth as in it.

Experiments also lead us to the same results with the dentine. If, by the aid of an acid, we decalcify the dentine, it becomes transparent and acquires the aspect and consistence of cartilage. When the dentine is incompletely decalcified, it resembles, minus the brown tinge, certain kinds of dentine altered by caries. Yet, at a more advanced stage of the disease, carious dentine is distinguished by less consistence, and, moreover, by peculiarities of structure, inasmuch as the action of acids alone is not enough to produce caries. It ought not, therefore, to be any longer doubted that the transparency of carious teeth should be attributed to the loss of their calcareous salts.

Mr. Tomes and, after him, M. Magitot have endeavored to explain this transparency otherwise. Mr. Tomes attributes it to the calcification of the fibrillæ which he discovered in the interior of the dentinal canaliculi. In fact, we also have been able to verify very often, and notably at the borders of the diaphanous zone, in the direction of the still sound dentine, the existence of a considerable number of minute cavities and of granulations ranged side by side, formed by cal-

careous salts and situated in the interior of the dentinal canaliculi.

Nevertheless it is impossible that the transparency should be due to the presence of these concretions, for we do not always meet with them, and when they do exist they are not found in every part of the transparent substance. They generally show themselves only in the form of a very slender zone at the limits of the portion of the dentine altered by the malady. It is easy to recognize in sections for the microscope that the transparency does not exist except where these concretions are seen, and that these same concretions form no part of the appearance which the tissue presents to the naked eye. Finally, it is easy to demonstrate *a priori* that these concretions cannot in any manner cause the transparency of these tissues. They could do so only by rendering them more homogeneous; that is to say, the matters deposited in the canaliculi ought to have the same index of refraction as the intercellular substance; the boundaries of the canaliculi would thus become, in the sections, paler and less obscure. The opaque aspect of the dentine in its normal state depends, at least in part, upon its structure. It is composed of parts which have different indices of refraction (the canaliculi and the intercellular substance), and which alternate regularly in position. But the concretions contained in the dentinal canaliculi ought rather to produce an opposite effect. In fact they are distinguished under the microscope by their dark margins, which proves that their index of refraction is different from that of the surrounding substance. They are, moreover, dispersed in little parcels, which increase the inequalities of the structure and lessen the transparency. In this connection we here remark the opacity which is produced in the tissues by minute globules of fat, ranged side by side, whose power of refraction is well known. If, in spite of this, the tissue remains transparent, we can explain the fact only by admitting that the disappearance of the calcareous salts has much to do with it, and it cannot be sensibly affected by slight inequalities of tissue.

We shall recur, in the course of this treatise, to the origin

of these calcareous concretions in the canaliculi, and upon the effects which MM. Tomes and Magitot have sought to attribute to their presence. We confine ourselves, for the moment, to asserting that the transparency of the carious dentine cannot at all be attributed to them.

It results, from what we have just said, that the cones, formed of a brownish and more diaphanous substance, make an integral part of the commencement of the work of decay, and should not be considered as a peculiar morbid condition preceding the caries properly so called. All can easily verify this for themselves by examining a great number of sections of carious teeth, for thus the different forms and periods can be followed and compared, from teeth where the cones are hard and where doubts may exist, to those whose cones are formed of a substance very distinctly softened and on the road to decomposition.

Microscopic Changes of the Dentine in a Carious State.

The microscopic changes which are undergone by dentine during the work of caries are of great importance in resolving the doubts which exist upon the nature of this malady, and especially in ascertaining whether or not organic action is to be regarded as among its causes.

We have established hereinbefore (in our review of what we actually know), that different authors have ascertained the existence in the dentine of histologic changes, upon the nature of which, nevertheless, they are far from agreement. Perhaps their differences would have disappeared if more importance had been attached to the manner in which the tissue was destroyed. We distinguish in dentinal caries two periods which cannot be rigorously defined; the preparatory *period of decalcification and softening*, during which the microscopic changes in question are to be observed; and the *period of direct decomposi ion.* Up to the present time it has been the custom to admit in general that the dentine, deprived of its calcareous salts, is dissolved by a sort of putrefaction. But it is not difficult to demonstrate that the influence of

leptothrix is very great in this work of destruction, inasmuch as it penetrates very deeply into the clefts and interstices of the decalcified dentine, which it reduces into small fragments. It is equally probable that this same *leptothrix* plays, by its extension, an active and direct part in the absorption of the carious tissue.

We shall demonstrate farther on that a great part, if not the whole, of the microscopic changes observed in carious dentine should be attributed to the introduction of the elements of *leptothrix* into the dentinal canaliculi, and in part into the intertubular substance. We will first examine the *phenomena which characterize the direct decomposition of the tissue.* We follow, it is true, a method just the opposite of that which the changes themselves have taken. Yet this offers no inconvenience, for the knowledge of these phenomena is indispensable in order to comprehend the changes which precede the caries.

If we examine the disorganized substance which covers the superficies of a carious cavity, and which, moreover, presents an acid reaction, we are truly astonished at the quantity of elements of *leptothrix* which are found there. The superficial layers, with the exception of some particles of food, are formed exclusively by the granular masses, and by the filaments of *leptothrix.* On removing these we come upon layers which possess sufficient consistency to permit us to make sections. These latter, as is shown in Plate II, Fig. 2, consist of irregular minute fragments of carious dentine of a brown color. They are enveloped and united by masses of *leptothrix;* above all, granular *leptothrix.* In the layers which lie still deeper the volume of the dentine increases; the *leptothrix* diminishes in such a proportion that the dentine here forms the principal part. We see, then, in the carious portions, colored brown, irregular chinks and interstices filled with *leptothrix* and its elements (Plate II, Fig. 1). This arrangement may well be compared to the canals and veins which are exhibited by certain stones. The *leptothrix* always diminishes in proportion to the depth; yet sometimes it is found at a remarkable depth, where it takes

a direction parallel to the dentinal canaliculi. We recognize very clearly this arrangement in sections of decalcified teeth, or in those ground thin with pumice. The images obtained in this manner do not permit us to doubt that these fungi by their extension have deeply penetrated the dentine, and have not confined themselves to simply filling pre-existent cavities. We find these latter nowhere, and we shall prove by and by that the minute dentinal canaliculi constitute the principal roads by which the *leptothrix* penetrates the dental tissues.

We often observe in sections islets which are filled with the finely granular matter of the fungus (Plate II, Fig. 6). The origin of these islets is easily explained by the direction of the sections which cross a conduit filled with *leptothrix*, and which, in consequence, offer the image of an isolated islet. We see there, moreover, other conduits which correspond with the surface. Up to the present time observers have confined themselves to proving the presence of the *leptothrix* in the carious cavities of the tooth, but without assigning it any influence in the work of decomposition. They have not noticed the introduction of the *leptothrix* into the softened substance of the dentine; and its presence in the carious cavities has consequently been considered as accidental and without importance. According to our observations we cannot refuse to admit that the proliferation of the fungus plays an important part in the decomposition of the dental tissue. What explains the ignorance of authors upon this point is that they confounded the vegetable granulations with the organic matters in decomposition, and that the elements proper to *leptothrix* passed unperceived. The reaction with iodine and the acids, which produces a beautiful violet color, as well with the granular masses as with the filaments, leaves no doubt about the nature of the granular *leptothrix*.

The figures and their explanations of Klencke, upon the penetration of the *protococcus dentalis* into the dentine, have a certain analogy with the images which we have just described above. The analogy, nevertheless, holds only as to

the mode of penetration of the cells, as he calls them, into the interior of the dentine. His Figure 15* (loc. cit., S. 57), might cause it to be thought that he had under his eyes the same image as we. Yet all that concerns, in these considerations and in these sketches, the form, &c., of the extension of these parasitic plants is, as we have already remarked, but the work of the imagination. The opinion of Ficinus, who figured at the surface of the carious dentine a considerable number of vibrios, called by him *denticolæ*, is explained in the simplest manner by the theory of M. Hallier, if he is correct. According to this author the granulations of the *leptothrix* are spores which have come to a state of repose.

In our researches upon carious teeth we have, it is true, seen the granular masses of the *leptothrix* stationary, and in proportion but a small quantity of granulations in movement. Nevertheless we believe that there may be great variety in the cases, and that, in given circumstances, we may come across considerable masses of spores dispersed and moving. The observations of Ficinus will thus become conformed to ours, when it will be necessary to consider the presumed infusoria as scattered spores of *leptothrix*.

Let us pass now to the examination of the *changes which take place in the dentine before direct decomposition of the tissue.* The softened dentine of a brownish color and of a feeble consistence, situated under a carious surface, presents, after removal of the masses of *leptothrix* which penetrate there, peculiar changes in the dentinal canaliculi. These changes become in general more and more perceptible as we proceed from the depths of the dentine to its surface. It is easy to see in cross-

* We have just learned that M. Georges Pouchet had expressed a similar opinion to ours upon the nature of the granulations of *leptothrix*. He considered them as one of the phases of development of the plant. This author has not noticed movements in the granulations which compose the granular masses, and he has concluded from this that they are always immovable. The movements which others have observed may be caused by vibrios which have penetrated the granular mass. New observations will show if we must receive the opinion of M. Pouchet, or that of M. Hallier, who thinks that the granulations of *leptothrix before coming to a state of repose*, move through the liquids in every direction, under the form of movable spores.

sections of teeth *that the canaliculi become very gradually larger, till they reach a considerable size, by the accumulation in their interior of a finely granular substance.* The canals so enlarged present for the most part a double contour, invisible in the normal state, a fact which indicates that the bore is bounded by thick walls. The thickness of the walls varies, but less than the calibre of the canals. Taking for our point of departure the portions which remain sound, we can observe in the sections the passage of the dentinal canaliculi from those without distinct walls to those whose walls are thickened, and whose dilatation goes on increasing by means of the accumulation of foreign substances (see Plate II, Fig. 2). In the latter case, there may still exist a wall distinct from the material contained in the canals; nevertheless, when the dilatation is very great, it may happen that this wall entirely ceases to be visible. Finally, if, in other cases, the canaliculi are but little dilated, while the walls are much thickened, we observe rings quite large, brilliant, and crowded upon each other, which have a brownish-yellow color, like the interposed substance. Close observation is necessary to distinguish the granular contents from the wall, which presents a brilliant aspect (see by the aid of a feeble magnifier Plate II, Fig. 3, where the walls are not at all visible).

At times the dilatation is carried so far that the canals, crowded together, not only touch at their circumferences, but become reciprocally flattened. We then observe in transverse sections polygonal instead of circular figures. At first sight, we might be disposed to think that the canaliculi become gradually obliterated by the successive thickening of the walls, according to the opinion of M. Neumann,* while Mr. Tomes compares the dentinal canaliculi with thickened walls to pipe-stems, and does not admit of complete obliteration. Nevertheless, we have come to be convinced that in all cases the tubes of the canaliculi are increased and filled with a mass which ordinarily will be finely granular and sometimes homogeneous, surrounded with more or less thickened walls.

* See loc. cit. Archives de Clinique Chirurgicale, t. vi, p. 1.

The principal reason which has caused M. Neumann to believe in the obliteration of the canaliculi by the successive thickening of the walls, is the images which are obtained after impregnating the preparation with carmine. The thickened walls do not take the color from carmine, while the matter contained in their interior is sometimes very strongly colored by it, and is thus very clearly distinguished from the walls. Sometimes, nevertheless, the contents are but slightly colored; it is then difficult to distinguish it from the thickened and brilliant wall, which gives rise to the belief that the canal is completely obliterated; but an attentive examination will always reveal the true state of things. The most remarkable varieties of coloration by carmine manifest themselves in the intertubular substance. In the normal state this substance is colored, feebly it is true, by the carmine; in the carious portions, on the contrary, and particularly when the brown color is strongly marked, this substance entirely resists coloring, so that these parts, including the dilated canaliculi whose contents remain equally inaccessible to coloration, contrast by their yellow hue with the surrounding parts colored red. On the contrary, in other circumstances, this same substance will take the color. This is the case with preparations made from the superficial layers, where the intertubular substance shows itself spotted throughout with very fine granulations. It may be said that the brown color is opposed to the red of the carmine, for this latter is perceived nowhere where the brown is strongly marked. We must not, therefore, place any great importance upon the coloration with carmine. We cannot share the opinion of M. Neumann who distinguishes two kinds of changes: 1st, obliteration of the canaliculi by successive thickening of the walls; and 2d, thickening of the fibrils contained in the dentinal canaliculi, and their division into successive cellular elements.

As for us, we attribute all the changes to a gradually increasing dilatation of the canaliculi by the formation of a finely granular substance which is more or less strongly colored by carmine, and *to a thickening of the walls of these same canals.*

In longitudinal sections, which rarely furnish images as distinct as oblique ones, we often see the contents of these dilated canaliculi reduced to the condition of small threads which at times become separated by minute intervals. Thus the dilatation of the canaliculi may become very considerable; but we find the threads in the canals already slightly dilated, and, in this case, carmine colors them a bright red (they correspond to the cellular elements which, according to M. Neumann, come from the thickening and division of the dentinal fibrils). In cases where the contents of the canaliculi does not take the carmine and, as well as the intermediary substance, presents a yellowish-brown shade, we perceive, in general, the canaliculi thickened only in a confused manner in the longitudinal sections; we can prove only that the dentinal canaliculi are badly defined, and that their contours are replaced by longitudinal striæ but little marked.

Analogous images under the form of bundles of rods, but in general of a smaller diameter and rebellious to the action of carmine, arise from deposits of calcareous salts in the canaliculi. We shall recur again to this subject farther on.

As M. Neumann has already observed, we can easily isolate the thickened dentinal canaliculi by macerating them in nitric or hydrochloric acid, just as is done for the normal ones (Plate II, Fig. 5). It is not rare to observe in the same canal the passage from the minute dimensions of the normal state to a pathologic thickening (Fig. 5, *b*). The isolated canals also present differences in the degree of coloration by carmine, and very often the division of their contents into threads can be recognized. The contents of the canaliculi often projects beyond their ends, and is seen under the form of a prominence with fine granulations, or else as a brilliant and viscous drop; in general the extremity of the canaliculi is then contracted. Sometimes, also, there can be distinguished through the walls in isolated canaliculi the contents composed of fine granulations.

Another peculiarity belonging to the thickened canaliculi consists of partial varicose dilatations and the sinuosities

which they present; this contributes towards rendering them susceptible of acquiring at these points a relatively considerable thickness.

The mean diameter of the thickened canalicule of a tooth was from .003 to .006 of a millimetre; some presented a much greater diameter, notably at the thickened and varicose points; the normal canalicule of the same tooth showed a diameter of only from .001 to .0015 of a millimetre. To form an opinion upon the nature of the changes just mentioned, it is of the highest importance to well consider the *condition of the dentine in the caries of natural teeth of implantation.*

The solution of this question will lead us to know if the changes are in part or wholly of a vital nature, or not. M. Neumann has expressed the same opinion, for he has declared that his conclusions would cease to be true if it should come to be proved that, in the caries of natural implanted teeth, the same changes take place as in living teeth. It is a well-known fact, long since observed, that false teeth, whether procured from man or made from the ivory of the elephant or hippopotamus, decay in the mouth as well as the natural teeth. Caries, indeed, establishes itself very quickly in these false teeth, and begins ordinarily in the points where the teeth are fastened upon the plates, or kept in place by the aid of wires. These places constitute, for the development of morbid phenomena, points of departure as favorable as the clefts in the enamel, or interstices in the teeth.

The partisans of the chemical theory of caries of teeth have always cited, as proof of their opinion, the caries of natural teeth of substitution. Nevertheless it could be objected that there is but an external analogy between the caries of these teeth and that of living ones, and that there may exist between the two essential histologic differences. This is the opinion of M. Neumann. He found, especially in examining a piece of ivory inserted in a bone and attacked by caries, that the characteristic changes of the dentine, as they have been described, were wholly wanting. He concluded from this that the caries of artificial teeth of ivory

may, in all probability, also not resemble that of the natural ones. On the contrary, we have remarked, in examining several teeth made of hippopotamus ivory, as well as three human teeth of substitution which had all decayed in the mouth, that the microscopic changes of the dentine, as they have been described, take place equally in these artificial teeth. In every case the canaliculi were more or less dilated, sometimes even extraordinarily so, and their contents were generally susceptible of being colored by carmine. Above all, in preparations made from hippopotamus ivory, we were able to observe these changes in the most marked manner (Plate II, Fig. 6). The isolated canals were in part very much thickened and presented the varicosities which we have spoken of. At the greatly dilated points these canals attained a diameter of .009 of a millimetre. There were even some of them which measured as much as .015 ; their contents were finely granular and were easily colored by carmine (Plate II, Fig. 7). It is true, we did not find in these the elements in the form of threads, but it is equally true that they are not always found thus in caries of the living teeth. Nevertheless, we have observed these same thread-like objects in the canaliculi of carious pivoted human teeth. The threads then do not form special elements, and the mass which fills the dilated canaliculi, and which is susceptible of coloration by carmine, ought not to be considered a substance of a different nature. In teeth made from hippopotamus ivory we do not see the walls of the canals thickened as in human teeth of substitution. In fact, the pieces made with human teeth of substitution present no difference from the preparations made from natural teeth.

Aside from these considerations there exist still other reasons for combating the opinion of M. Neumann, who admits a vital action in the changes we have just mentioned.

M. Neumann himself declares that the transformation of the dentinal fibrils, deprived of *nuclei*, into cellular elements ranged one after the other, appeared extraordinary. Farther, as to the cells, we cannot reasonably expect to see their dimensions vary within too narrow limits. But, indeed, the

threads are already seen in canaliculi which exceed but slightly their normal thickness, as well as in those which have acquired a considerable dilatation, and the volume of the threads corresponds to the dilatation of the canaliculi. From time to time we see the contents of the canaliculi divided into minute and rather short fragments; in other cases divisions are noticed only here and there at great distances, and often they are entirely wanting for a large extent.

It would as well be permitted to suppose that, by the fact of maceration in mineral acids, the cells are completely destroyed, and that the threads no longer exist. But it is by no means so; the threads are excellently preserved, a fact which proves that they are composed of a material more resistant than the substance of which the animal cells are formed.

We profit by this circumstance to call attention to the fact that in artificial teeth caries extends equally and by preference along the dentinal canaliculi.

In the human teeth of substitution which we have had the opportunity of examining, the caries did not commence on the natural surface, but rather on one which had been cut away; thus the formation of a cone became impossible, inasmuch as this can be produced only by the convergence of the dentinal canaliculi which proceed from the surface into the central portion of the tooth. In spite of this we could perceive clearly that, at the points where the dentinal canaliculi were perpendicular to the surface, the changes had penetrated much more deeply than there where the canaliculi presented a direction parallel to the surface.

If, in accordance with what has just been said, the changes mentioned do not owe their origin to a vital action, it behooves us now to inquire into their true nature.

One might think, *a priori*, that they had been occasioned by the action of acids. Nevertheless, this cannot be proved experimentally, and as Mr. Tomes has well said, we do not succeed in any manner in imitating artificially the caries of the teeth. The experiments of M. Magitot, in which he has succeeded in producing profound changes in teeth submitted

for a very long time to the action of diluted acids, are not at all conclusive, inasmuch as they are not supported by any microscopic examination. In fact, examination under the microscope is indispensable, because by this alone can we verify the changes characteristic of caries. In the second place, it is possible that the elements of *leptothrix*, which take an essential part in the final destruction of carious dentine, occasion as well the changes of the canaliculi which precede this destruction. This opinion alone is capable of explaining the changes undergone by artificial teeth, and is completely confirmed by the facts; for the contents of the dilated canals presents the same violet reaction as the *leptothrix*. In preparations in which are found together elements of *leptothrix* and thickened canals, we obtain in a like manner the violet coloration, which gives us beautiful images of the contents of the dilated canals.

It is useless to remark that we have satisfied ourselves that with the normal dentine such a reaction never takes place. Iodine and the acids color it nothing but yellow. The reaction is independent of the coloration of the contents of the dentinal canaliculi by the carmine. In transverse sections of the canals the rounded and brilliant disks, which are rebellious to the coloration by carmine, give the reaction, as well as the dilated canals which contain a finely granular matter susceptible of taking a vivid color from carmine.

We easily distinguish, in the first, the contents from the walls, and these contents have also taken a finely granular appearance.

The difference of coloration by the carmine does not then establish any essential difference between the minute canals. It, perhaps, has for its cause, in part at least, a differing state of development in the spores of the *leptothrix*. We have at least noticed that the masses of *leptothrix* taken from the surface of the tongue, and older, to judge from the strong adhesion of their elements, are less strongly colored by carmine than the more recent masses whose elements are more easily isolated. Iodine alone colors the canals yellow. There are, nevertheless, cases where the violet reaction has taken place

by the simple addition of iodine. The fungi situated at the surface are generally colored more strongly. The concentrated acids, in which teeth are placed for the purpose of decalcification, appear to render the reaction impossible. This is the reason, without doubt, that M. Neumann obtained no violet reaction upon prepared portions of decalcified teeth.

There is, then, no manner of doubt that the elementary parts of the fungus penetrate into the interior of the canals, and there develop in a manner to acquire a relatively considerable diameter. It also results, from the very fact of the dilatation of the canals, that the appearance of the fungus is not accidental, and that it is not by a purely passive action that it invades the canals. It is necessary that there be a proliferation of spores infinitely minute and innumerable of the fungus to effect the dilatation of the dentinal canals. It is, moreover, very important that the elements of the *leptothrix* should have, at a certain stage, a mobility of their own, in virtue of which they easily penetrate the interior of the canals. As for the rest, we have met in the canals with only the granular masses of the *leptothrix*, and never the filaments which appear to show themselves only at the surface.*

According to experiments actually made are also explained the *formation of conduits and clefts filled with granular masses of leptothrix, which are found in the superficial layers of carious dentine.*

They spring from the dilatation, gradually increasing, of

* The fungi described by MM. Wedl and Heider (see Wedl "upon a fungus developed in the dentine") (Comptes rendus de l'academie de Vienne, 1864, t. l, p. 173–193) have, according to the description of these authors, nothing in common with the *leptothrix*. These develop, after some days, in the cement and dentine of sound teeth which have been extracted and placed in water. The fungi from the cement penetrate the dentine, after ten days, to a depth of from .2 to .25 of a millimetre. Portions of dentine which were exposed to their invasions were, after three or four weeks, pierced like a sieve. These experiments come to the aid of ours, inasmuch as they prove that fungi can develop in the cement and dentine, even when these tissues still possess all their calcareous salts.

The soft filaments which Mr. Tomes has found in the interior of the canals are probably too tender to resist the invasion of the elements of *leptothrix*, and appear therefore to be promptly destroyed.

certain minute canals. Under the influence of this morbid action, the walls and a part of the surrounding tissue completely disappear. It will, then, be wrong to conclude from this the introduction of the fungus into pre-existing fissures. We can, in fact, observe all the transitions between the dentinal canals greatly dilated and the conduits filled with *leptothrix*, and thus assist at the development of these conduits. At the outset these latter always follow a direction parallel to the dentinal canals; in consequence, at certain points, more marked dilatations are found corresponding to the varicosities of the dilated canals. Neighboring conduits may meet at these points and anastomose with each other. By the incessant development of *leptothrix* the softened dentine becomes decomposed into irregular parcels, which, towards the surface, become more and more minute and finally separate, completing the destruction of the tissue.

We conceive that the dilatation of the dentinal canals, found in the tissue situated immediately below the carious surface, may be more or less pronounced and not always reach the highest degree of development. If, in certain canals, the extension of the *leptothrix* is more considerable, the intermediate parts may be isolated and undergo decomposition, even when the canals have undergone but a moderate extension. The decomposition of the substance may, it is true, likewise commence at the very beginning of the carious surface, which is constantly covered with a prodigious quantity of *leptothrix*. It frequently happens that, in the layers of the surface, the *leptothrix* also infiltrates the whole intertubular substance, which then presents a granular appearance, and the contours of the canals thus become very confused. In these cases iodine and the acids produce upon the whole tissue a violet reaction.

The thickening of the walls can, it is true, have for its cause an action purely mechanical following upon the distension of the canals and the consequent thickening of the environing substance. Yet, we must remark, that we have observed similar walls where the canals have not been at all dilated. In cases where the action of caries has just com-

menced, we have seen a portion of the canaliculi moderately dilated and filled as usual with *leptothrix*. Other canals, on the contrary, had a normal calibre; they may even have been a little narrow, very pale, and surrounded with glistening walls; whilst the walls of the dilated canals were difficult to distinguish. Nevertheless, we are not quite sure that the phenomenon is analogous to that which presides over the dilatation of the canals. By the aid of maceration in hydrochloric acid the canals are easily isolated; they present their normal delicacy; whilst there, where the canals are dilated, the walls are isolated at the same time with the canals; in the former case the wall evidently offers less resistance to the action of the acid than in the latter.

According to Mr. Tomes the thickening of the walls in caries is the result of the regeneration of the contours of the organic cellules of the dentine.

M. Neumann declares, on the other hand, that the dentinal walls are thickened at the expense of the intercellular substance. These authors explain differently the manner in which dentine is formed by the aid of dentinal cells, and it is very difficult to say what is or is not the truth among such different statements. The opinion of Mr. Tomes is based upon the following supposition: According to him the dentinal cells are penetrated with calcareous salts, except an interior portion which is left free, and which forms the dentinal canaliculi with the fibrils which are found there. At the same time there is seen to form a certain quantity of intercellular substance which is impregnated, as well as the cells, with calcareous salts, and becomes so fused together with them that their proper contours disappear.

M. Neumann, on the contrary, considers all the intercellular substance as the product of a secretion: as for the cells of the dentine they send out very delicate prolongations which go to form the fibrils found in the canaliculi. However this may be the question still remains how the connection of the fused cells comes to be dissolved; or, if the opinion of M. Neumann is preferred, from whence springs the thickening of the dentinal walls? We have already remarked

that acids give rise to no such alterations. To recapitulate, it appears to us very probable that the thickening of the walls of the dilated canals is produced mechanically, on account of the pressure of the surrounding substance. Here, nevertheless, we are obliged to acknowledge that in some rare cases there are found walls thickened without the canals being dilated, and we confess our ignorance of the cause. Perhaps we may be permitted to suppose a chemical action by the elements of the *leptothrix* upon the environing tissue.

We have already remarked that during the action of caries there are often formed calcareous deposits in the interior of the dentinal tubes, deposits which Mr. Tomes and M. Magitot have regarded as of great importance. They are seen ranged singly, or in groups, under the form of minute threads, or bundles of them, more or less long; or else under the form of separate cylindrical granulations. On submitting them to the action of acids they dissolve, and leave, most frequently, an organic residue, which preserves the same form.

At times the masses of *leptothrix* contained in the dilated canals are also impregnated with calcareous salts; but oftener we meet these deposits in the undilated canals of the deep layers of dentine changed by caries. We likewise find from time to time minute calcareous granulations in the interglobular spaces of the dentine. They are observed most frequently in sections of carious teeth in which the changes are not far advanced. In these cases they are always found in a zone which surrounds this altered portion of the dentine whose canaliculi are dilated, and show a very intense brown color (see Plate I, Fig. 4, which represents a portion of the dental section pictured in Fig. 3; we see here that the calcareous deposits do not begin to appear until at a certain depth from the surface). If the change of the dentine has but just begun we sometimes meet the calcareous deposits throughout the greater part of the cone. We have already demonstrated that the transparency of carious dentine cannot be attributed to the presence of calcareous salts in the interior of the canals. These deposits should rather diminish

the transparency; and yet the zone which contains them is more transparent than in the normal state. We can therefore attribute it only to the abstraction of a portion of the calcareous salts. These deposits of calcareous salts in the interior of the dentinal canaliculi are considered by Mr. Tomes, and after him by M. Magitot, as the product of a vital action. But inasmuch as these same calcareous salts are likewise found in carious artificial teeth, we can also adduce here all the objections already made against the vital character of the other changes which we have described.

We are still more inclined to believe that these calcareous deposits are formed by a purely chemical process; that is to say, by the residue resulting from the solution of the calcareous salts by contact with acids.

In the work of caries a portion of the calcareous salts of the teeth is always dissolved out; these same salts, so dissolved, must by diffusion penetrate the canals towards the cavity of the pulp; there in contact with the neutral or alkaline liquid which fills the interior of the canals, or which penetrates the dentinal fibrils, a precipitate is formed. If we drop upon the section of a sound tooth, placed under the microscope, a little concentrated acid, then, shortly after, some drops of water, we see a great number of needle-shaped crystals immediately form, which arrange themselves in the form of rosettes.

These crystals must be composed of phosphate of lime. In glasses, in which we have for some time preserved carious teeth in water slightly acidulated, we have seen an abundance of these same crystals precipitate themselves upon still farther weakening the solution by the addition of water. The calcareous salts which have been dissolved by the acids are precipitated by the simple addition of a neutral liquid, and still more by the mixture of a liquid slightly alkaline. From this it is easy to understand why the calcareous deposits are always found at the extremity of that part of the dentine which is altered by caries; and it is not necessary to admit that they are formed in the pulp-cavity.

Mr. Tomes compares the calcareous deposits which form

at the extremity of the diseased dentine to the work of exfoliation in the parts bordering upon a portion of necrosed bone or gangrened tissue. In the two cases the reaction takes place in the surrounding sound parts, with this difference, nevertheless, that in dental caries there is no elimination of the diseased tissues

M. Magitot, on the contrary, believes that the calcareous deposits spring from the pulp; this being irritated gives out a calcareous exudation which at first fills the canals, from without inwards, and which, in fine, according to circumstances, is deposited as dentine of new formation upon the interior surface of the pulp-cavity. It is, nevertheless, absolutely proved that the calcareous deposits in the interior of the canals cannot be identified with the new layers of dentine which are formed at the surface of the pulp-cavity. These formations, in fact, as well as the normal dentine, take their origin from the dentinal cells of the pulp. If the calcareous deposits arise from the pulp, why are they at first so far from it? and why are they not always found in its immediate vicinity? As for the rest, all explanations of this class are formally refuted by the formation of calcareous salts in the caries of artificial teeth, and it is therefore useless to seek for other explanations. Calcareous deposits are more abundant in proportion as the progress of the caries is slower, and they develop themselves in an especial manner when the caries remains at rest during a certain time.

The protection which these calcareous deposits seem to furnish to the dentine can, consequently, be of no great account. As soon as the caries makes new progress, they are dissolved, and probably with more facility than the normal calcareous salts of the dentine. From the fact that these deposits manifest themselves more particularly when the march of the caries is slow, it has been concluded that they oppose the morbid action; while according to our views the slow march of the caries has, on the contrary, for its effect, the formation of the calcareous deposits.

It remains now to examine *if the phenomena which we have just described, and which relate to the action of acids and of the*

leptothrix, are the only ones which are to be observed in caries of the dentine, and if, hereafter, we are authorized to deny all intervention of vital action. Although we have demonstrated that all the changes described heretofore do not have for their base any vital action whatsoever, we are not permitted, *a priori*, to reject it as impossible.

We can have no doubt of a certain vital action in an organic tissue like the dentine, even when it has reached its complete development, even if these vital properties are but little marked. We can very well conceive that the delicate fibrils which, according to Mr. Tomes's discovery, fill the interior of the canals, and preside, in all probability, over the phenomena of nutrition in the dentine, may become changed by an abnormal excitation and thicken like cellular elements irritated or inflamed, and produce by division new elements, as M. Neumann has established. It is evident that we must admit changes of this nature at the outset of the diseased action, and before the elements of the *leptothrix* have penetrated into the dentinal canals and destroyed the fibrils which they find there.

We have already established that the first changes manifest themselves in the dentine, when the enamel is carious throughout its thickness, though there may not be even the slightest loss of substance at the surface of the tooth. As the *leptothrix* is obliged to traverse the enamel to reach the dentine, and as, in our researches, we have found no element of *leptothrix* in carious enamel, as long as the caries has not attacked the surface of the dentine, we should expect to observe, at this first degree of the malady, isolated changes of the dentine completely foreign to the action of the *leptothrix*. To the naked eye, the dentine offers, at this period of the malady, the same brownish appearance as later; we remark also that its consistency is not sensibly diminished, except at the surface, in the vicinity of the enamel, and then only in a very thin layer; its hardness increasing rapidly as we go towards the deeper portions. In most cases we have found, at this stage of caries, no alteration of the canals; their dilatation is normal, and they are but rarely to be distinguished

from the intertubular substance by less marked contours. In consequence, this dentine gives no reaction which indicates the presence of *leptothrix*. Yet, exceptionally, we have found in the superficial layers changes resembling those which we have heretofore described, but they have been very much less developed. Sometimes the canals were little dilated, and their walls were thickened at certain points. In the small number of cases, where we have had the opportunity of verifying this result, we have not been able to obtain any reaction capable of indicating the presence of the fungus; nevertheless this does not prove the absence of the *leptothrix*, inasmuch as at that time we happened to use too strong acids, and so failed of the reaction, even when the presence of the fungus was certain. As the changes existed only in an exceedingly thin layer under the surface of the dentine, the substance capable of giving the reaction was present in but a very minute quantity. We think, nevertheless, from the identity of the phenomena which were present in this case with those which determine the introduction of the *leptothrix* into the canals, that they depend upon the same cause. It is true that we have not succeeded in proving the presence of the *leptothrix* in the substance of the enamel, but its surface was usually covered with a granular mass of *leptothrix*. Yet it is possible that, on account of the extreme minuteness of the elements of the fungus, we have not been able to see in the enamel the very delicate chinks through which the fungus would have to travel to reach the dentine, and there develop in a more favorable soil. This point, nevertheless, will agree with still other observations.

In all cases it results from this that the introduction of the fungus into the dentine does not take place during the first evolution of the caries; at this epoch of the malady, we remark only the loss of calcareous salts, and the decomposition of organic substances, then diminution of consistency, transparent appearance, and brownish color.

At this stage the histologic examination permits us to view, in the structure of the dentine, no marked change. We cannot say that there are already calcareous deposits in

the canals, inasmuch as we have not given sufficient attention to that point; nevertheless these deposits may be early formed, even at a time when no marked change of the tooth is yet perceptible.

From what has just been said we conclude that there exists, up to the present time, no observation which authorizes us in admitting in caries of the teeth an active reaction on the part of the dentine—an inflammation, for example. We assert that this caries comes not from such causes, although it is impossible to deny with certainty that there exist slight histologic changes of the dentine, observed at the beginning of the malady, which are not due to the action of *leptothrix*. We ought to add here that the *leptothrix* acts in like manner in the *destruction of the cement* by caries, when it has its seat at the neck of the tooth.

We have seen, in cases of this kind, the granular masses of the fungus buried in the chinks and excavations of the cement, just as we see them at the surface of the dentine. We have not been able to prove a particular change in the bony corpuscles; and, further, there is wanting every indication which can cause a suspicion of an inflammatory state of these elements. As the number of cases in which we have had an opportunity of examining caries of the cement is but small, we cannot draw from them general conclusions as to the absence of inflammatory changes. Such changes would not, however, be surprising, inasmuch as the causes of irritation of the periosteum of the root of the tooth, as well as the production of cementous substance of new formation, can be considered as ordinary consequences of dental caries.

III.

CONSIDERATIONS UPON THE PROGRESS AND SYMPTOMS OF CARIES OF THE TEETH.

Having described the anatomo-pathologic changes which take place in caries of the enamel, and of the dentine, we will now proceed to define in a few words the variations of the progress, symptoms, &c., of this affection, and to show that these variations are perfectly explained by the results of our researches.

First, the *different varieties* of the beginning of caries have received a considerable number of denominations, but we are obliged to confess that we have not found essential differences, and we think they can all be explained by a greater or less duration, by the variable resistance of the dental tissue, and by the lesions, more or less extensive, which exist from the first in the enamel. We have already remarked that there can be distinguished a form of caries *which is propagated more towards the surface*, and another whose character is to burrow into the deeper portions; these two forms do not offer any other essential difference. The caries called *dry* is, properly speaking, only the first degree of the work of the malady, when the dentine is as yet but incompletely decalcified, when no element of *leptothrix* has yet penetrated there, and no change has manifested itself at its surface. Then the enamel as well as the dentine is transformed by mechanical action into a rather fine, hard, pulverulent mass; while in the so-called fibrillary caries, the substance of the dentine, much softer, and as it were cartilaginous, appears to be composed of very fine filaments. This filamentous texture depends upon the great dilatation of the dentinal canals.

The tooth will remain in the state of dry caries the longer

in proportion as it shall offer by its density greater resistance to the invasion of the malady, so that the fibrillary or humid caries may perhaps at times never become established there. The carious substance is at such times marked by a very dark color.

When the caries, on the other hand, makes rapid progress in a tooth of little resistance, it may happen that the destruction follows promptly the preparatory changes. In this case the dry caries may pass wholly unperceived, or be observed but a short time; the brown discoloration will also be but slight. The enamel and the dentine are in such cases changed into a soft, whitish, pulpy mass, and the tooth promptly reaches its total destruction.

There is distinguished a form of caries which attacks the necks of the teeth. It attacks almost always, and at the same time, all the teeth in front, and more particularly those of the lower jaw. It forms at the necks of the teeth a smooth, gutter-like furrow. This is often so marked and so polished that one might say it had been made with a file. Generally it is only the incisors and canines which are attacked; yet, sometimes, this caries extends to all the teeth of a jaw, but the incisors and canines are always more strongly attacked than the molars.

Very often the gutters which exist across the necks of the teeth are of a normal white color, and wholly smooth, as if they had been polished. In other cases the surface of the gutters is smooth, it is true, but has the brownish coloring of caries. We have had opportunities of examining anatomically two teeth of this kind. Upon a section made longitudinally we have observed that, proceeding from the gutter, there was only a feeble trace of a brownish cone looking towards the pulp-cavity, for this reason, the changes which precede the caries of the dentine extended to but a slight depth, and were not marked. The density of the dentine was but little less than normal; there was, just below the surface, a slightly marked brownish shade. Under the microscope we observed in this superficial layer, as usual, the dentinal canals filled with *leptothrix*. The surface was

smooth, and it was impossible to find there a layer evidently softened. The enamel had been wanting for a long time in the greater part of the gutter; but, on the side of one tooth, we observed that the gutter, in becoming of less and less depth, extended for a short space across a bit of carious enamel of a brownish color. Upon the other tooth the gutter stopped suddenly with well-defined outlines on every side. In a vertical section it presented the form of a triangle with its base turned outwards, and its vertex towards the cavity of the pulp. On the lower side of this triangle there appeared a brownish cone directed towards the pulp-cavity. Upon the interior surface of the pulp-cavity, at the place corresponding to the gutter without, there was found at the extremity of the brownish cone a projection formed of dentinal substance, of new formation, which had penetrated the pulp-cavity to a considerable depth.

In this observation it was evident that the caries was of a very slow progress, but had, notwithstanding, all the essential characters of this affection. The surface changes took place slowly, and the affected portions were with proportionate slowness involved, while the surface was kept constantly smooth by friction with the brush. The polish of the surface is sometimes so great that it might be supposed to be effected by friction against a tooth; yet this is impossible for the neck, in consequence of the position of the teeth. To explain, therefore, the polish of the surface, we can invoke only the action of the brush, and the friction of the lips and of the tongue. It remains, nevertheless, to inquire if these gutters, with so highly polished surfaces, must be considered as stationary, as most authors think. There are cases where the teeth always preserve a white and polished surface, and in which, nevertheless, the affection makes incessant progress, but in a manner so slow that years often roll by before only a thin wall separates the caries from the pulp-cavity. The affection, arrived at this stage, ends by exposing the dental pulp, and the tooth is often broken at this point. Doubtless the progress of the caries can be retarded by dentine of new formation deposited upon the interior surface of the dental

canal, otherwise we should see, particularly in the incisors, this thin wall of dentine much sooner destroyed, and the canal opened. If we consider isolated facts of this kind, we feel little disposed to take these phenomena for symptoms of veritable caries; but by analogy with other facts, where the nature of the caries is shown, we are compelled to admit equally for these exceptional cases that we have to do with a caries whose progress is very slow, which, for a time, may be really stationary, and afterwards take on new life under the influence of a favorable cause.

Nevertheless, it should not be asserted that all cases of caries of the neck have this slow evolution. There are cases where its march is absolutely the same as in ordinary caries. It would appear that the cause of this caries is the denudation of the neck by the absence of the gum. Upon the slightly rough surface of the cement fermenting mucus and fragments of food are more easily deposited, and these same agents fixed between the gums and the neck of the tooth are less easily removed. It may then happen in cases where the injurious causes are weak, or the teeth of a special hardness, that it is just the necks of the teeth which are more likely to be affected.

In some very rare cases we notice a peculiar wasting of the incisor and canine teeth, attacking as well the enamel as the dentine, and which shows its greatest intensity upon the centrals. There, when the mouth is closed, the cutting edges of the teeth form arcs of opposite concavity, and show a longitudinal interval between them. For want of sufficient observations it is not possible for us to say if these morbid phenomena belong or not to caries. The form of the wasting does not permit us to attribute it to mechanical action.

Stationary Caries.

In what is called stationary caries reference is often had to dry caries only whose progress is very slow, or is distinguished by longer or shorter times of rest. There are, nevertheless, cases where the disease is really stationary, but this

can be only where the teeth possess great power of resistance, and when the caries has a very slow progress. It is, notwithstanding, necessary to distinguish the different stages of caries in which it becomes stationary.

In the dry caries, when there does not yet exist any change at the surface, it seems that the caries may easily become stationary. This is readily understood, inasmuch as it is enough to suppress the action of acids, the tooth having still sufficient hardness, and being still free from all attack of *leptothrix*. Yet it may sometimes happen, when the caries has reached a stage where the greater part of the enamel and a superficial layer of dentine are destroyed, that the malady is stopped. This is seen in molar teeth whose depressions are incompletely provided with enamel, and which show defects upon their surfaces. In these cases we see ordinarily, from the beginning of the malady, a great part of the surface of the enamel attacked by caries; the dentine may be still sound, and offer great resistance. While the enamel is so rapidly destroyed, as far as the surface of the dentine, the softening of this latter, and the loss of its calcareous salts, are carried to but a slight depth. The relation between the rapidity of the destruction of the enamel and that of the dentine is then, in such cases, the inverse of that which exists in the normal state. When the caries has attacked the surface of the dentine, which, in consequence of the defective structure of the enamel, takes place at once over the greater part of it, the dentine is but slightly softened, and to but a very little depth. The most superficial layers of the dentine are removed, and by friction upon the smooth surface the work of the caries is arrested, the surface becomes more and more polished, and offers less opportunity for the accumulations of mucus and particles of food undergoing acid fermentation; finally there results from all this a stationary condition. The tooth presents a polished surface, but of a brownish color, as if to attest that the substance at the surface has been the seat of caries.

The considerations presented by Mr. Tomes and M. Magitot upon the cause which determines the stationary state of

caries are founded upon the presence of calcareous deposits in the minute dentinal canals. As we explain the matter, the calcareous salts deposited in the canals should have the ability to arrest the work of the caries, and give the already softened dentine a greater density. Yet, as the formation of these calcareous deposits cannot be attributed to a vital action, we are led to believe that they are secondary, and that they become abundant only when, from some cause, the action of the acids has ceased; then the calcareous salts which existed in a state of solution are precipitated. Neither do we believe that the dentine can become harder in stationary caries, excepting, perhaps, the surface, where mechanical means, such as friction or pressure, may produce a slight condensation. To explain the facts it is sufficient to admit that the dentine had not yet lost its normal hardness, or at least had lost it in but a very slight degree.

In these cases of slow and stationary caries we also very often find the formation of new dentine at the inner surface of the dental cavity. We can explain this phenomenon by the fact of a long irritation which the pathological action of the caries exercises upon the pulp. It contributes very much in the given circumstances to the preservation of the tooth.

When the caries is farther advanced there are formed in the dentine cavities, generally rounded, which communicate with the surface of the tooth by a greater or less opening; or the morbid action occasions loss of substance more extensive, and without depth. Little by little the disorganization reaches the cavity of the pulp; this is exposed at some point, and very often, in consequence of its irritation, successive inflammations are excited which end in its destruction.

It has been observed that when the pulp is destroyed the caries proceeds much more rapidly, and from this fact the proof has been sought to be drawn that, as long as the pulp retains its vital properties, it contributes to the preservation of the tooth; while the contrary happens immediately upon its ceasing to exist. But the more rapid progress of the caries after the destruction of the pulp is explained by the fact of there then being a much greater surface exposed to

its action, inasmuch as now the destruction works in every direction, not only from the ancient cavity, but from the pulp-cavity which corresponds to it. It is not necessary, therefore, to attribute to the pulp a conservatory action for the tooth, excepting, indeed, the dentine of new formation which it builds up, and which really protects the tooth.

While the caries continues its ravages the walls of the cavity, which are formed by the sides of the crown, break down, so that the tooth is destroyed down to the level of the roots. Starting from this point we observe, in most cases, the caries take up anew a slower action, such that the roots which remain may be preserved for a long time in their alveoli. It may be that the friction which must be continually acting may be the cause of this, in part at least, opposing itself to the progress of the disease by offering a more polished surface. Another reason which seems to us still more important is that which is derived from the direction of the dentinal canals. These proceed at the surface of the teeth more or less vertically from the pulp towards the exterior, so that, taking this part for its point of departure, the caries is able to propagate itself easily to the interior, following the direction of the canals.

At the commencement of the surface of the roots, on the contrary, these little canals have a direction oblique, and parallel to this surface. Then, when the tooth is decayed away up to the root, the direction of the canals no longer favors the introduction of the acids and the elements of *leptothrix* into the deeper parts. This explains the slower progress of the caries when it reaches this point. In the same way may be explained the fact that caries is never seen to be developed around the walls of a canal artificially pierced at the neck of a tooth (Hulihan's operation); the little dentinal canals, following a direction parallel to that of the walls of the artificial canal, also in this case, do not permit the introduction of injurious elements.

The *sensibility of carious dentine* may be occasioned by a greater irritability of the pulp. Yet it is difficult to explain

why the superficial layers of the dentine are very often more sensitive than those which are deeper.

To Mr. Tomes this consideration appeared to have great weight. We observe, in fact, that quite frequently the least touch causes the acutest pain in the carious dentine, at a stage when the cavity of the pulp is still far from being reached. At such times the removal of the superficial layers of carious dentine occasions excessive pain; but as soon as this layer is removed the sensibility of the subsequent layers is seen to be very much less. The greatest sensibility ordinarily exists at the extremity between the enamel and the dentine. We especially remark this in the incisors at their acute angle, where the anterior and posterior surfaces come together. Mr. Tomes has concluded from these facts that the dentine itself is endowed with sensibility, and that this is not due, at least exclusively, to contact with the pulp. He believes that this sensibility is occasioned by the soft fibrils which he has discovered in the interior of the dentinal canaliculi; he does not consider them as true nervous fibrils, but thinks they may be agents of sensibility. This opinion cannot be reconciled with the actual state of physiology. Either the fibrils of Mr. Tomes are truly endowed with sensibility, and are therefore true nervous fibrils, or they have no nervous nature, and cannot transmit sensibility, inasmuch as this function belongs essentially to the nature of nerves. But every consideration is opposed to considering them as nerve fibrils, and their origin above all. They are prolongations of the cells of the dentine, a fact which establishes their analogy with the ramifications of osteoplasts, or the plasmatic cells of the cornea. Nerves have not been found in the dentine, and, in the absence of all anatomical proof, we must not be too hasty to attribute sensibility to it. Assuredly the facts we have mentioned would be easily explained if the dentine had a sensibility of its own, because then certain diseased parts would acquire more sensibility than others. This sensibility may be explained, perhaps, by a certain direction of the canaliculi, or at least by a more considerable expansion at the surface,

which may be more accessible to mechanical actions, and may transmit them to the pulp. Experiments, whose object should be to inquire into the rapidity with which the slightest contacts are followed by pain, would perhaps give new enlightenment upon the subject. But until nerves are discovered in the dentine, and clinical experiment has furnished us with authentic facts, we shall feel more inclined to attribute the sensibility to the irritated pulp than to the dentine itself.

IV.

CAUSES OF CARIES.

From what has been said it results that *two principal phenomena* manifest themselves in the formation of dental caries, viz., *the action of acids*, and the *rapid development of a parasitic plant*, the *leptothrix buccalis*. In the following chapter we shall have to examine more in detail the mode in which these agents proceed and the conditions of their appearing.

The action of injurious elements is favored by predisposing circumstances which consist mainly in the structure and in the incomplete development of the dental tissues. The influence exercised upon the formation of caries by constitutional anomalies and by certain coexisting maladies may be referred principally to two circumstances: first, we very often remark troubles in the development of the teeth during the existence of certain maladies, or when there exist constitutional anomalies. The tissue of the teeth is, in such cases, incompletely formed, and unsuited to resist the action of injurious agents; then local conditions of the buccal cavity may favor the formation of acids, as well as of the parasitic plant, the *leptothrix*. Likewise many maladies of the mouth and certain states of the stomach cause to arise in the buccal cavity an abnormal work of fermentation which is accompanied by a more abundant formation of acids, and favors the production of the fungi. The progress of the caries is equally favored when, in consequence of sickness or from any other cause, the saliva is secreted in too small a quantity, thus preventing the neutralizing or diluting of the acids.

I. Predisposing Causes of Caries due to the Form and Structure of the Teeth.

We have first to examine the incomplete development of the dental tissues, above all of the enamel and the dentine, which is a predisposing cause of the greatest importance.

In congenital anomalies of the enamel we may distinguish anomalies quantitative and anomalies qualitative.

The quantitative anomalies are manifested under very diverse forms. The surface of the enamel is irregular, presents inequalities and depressions more or less developed, and which may be few in number, or scattered over the whole surface of the crown. These teeth are sometimes designated as "honeycombed" teeth, from their resemblance to that article. In other cases we see the cutting edge of the incisors notched or toothed, and sometimes of a conical shape, both which forms are caused by deficiency of the enamel; or the teeth present parallel furrows crossing them horizontally.

The name of erosion is given to those lesions which show themselves at once upon several teeth, and yet they are but incomplete developments of the enamel which have of erosion only the form. Finally, the enamel is sometimes completely wanting upon a greater or less extent of the crown.

The anomalies just described must be only too favorable to the establishment of caries, inasmuch as the agents of an injurious nature deposited in the cavities and irregularities of the tooth can extend their action without obstacle, and much better than on a polished surface. The fissures of the enamel occasioned by sudden changes of temperature may exercise the same influence. Doubts have been raised upon the possibility of seeing fissures of the enamel caused by changes of temperature, but these fissures are sufficiently frequent. In many cases the enamel of the greater number of the teeth, and sometimes even of all, is seen covered with chinks in every direction. They are most frequently caused by sudden changes of temperature, but sometimes are due to a traumatic action. We have convinced ourselves of the

direct influence of the first of these causes by plunging the teeth alternately into hot liquids of a temperature about equal to that of hot meats, and then into iced water. It seems, nevertheless, that these fissures have less influence than the defects of the enamel upon the formation of caries, supposing that it possesses a normal density and hardness. We find, in fact, teeth whose enamel shows fissures in every direction, and which, after a long time, have not been attacked by caries. But if the fissures appear in teeth whose enamel is primitively less resistant, it is clear that they offer greater opportunity to the action of injurious agents.

The qualitative anomalies which depend upon an incomplete development of the enamel often coincide with the quantitative; they may, however, exist separately. They are distinguished, in general, by a less hardness and by an opaque appearance of the enamel. Mr. Tomes distinguishes two kinds: in one the enamel presents a brownish and dead color, showing itself more particularly upon teeth which are marked, as has been said above, with congenital fissures and depressions, and the excavations are marked in general by a somewhat darker color. The other kind presents itself under the form of white spots of greater or less extent.

In the first kind were discovered by Mr. Tomes deposits of minute calcareous granulations in the interior of the enamel prisms, at the same time that the peripheric layers of the prisms were impregnated with calcareous salts in a homogeneous manner. We speak here of an insufficient quantity of calcareous salts in the central portions of the enamel prisms, a circumstance which is but an exaggeration of the physiologic condition. In fact, according to Mr. Tomes, the central portions of the prisms in the normal state become impregnated more slowly with calcareous salts, and are therefore more promptly deprived of them by weak acids than are the layers of the periphery. In some cases Mr. Tomes observed minute excavations in the interior of the prisms of this incompletely developed enamel.

In the congenital white patches of the enamel Mr. Tomes found the fibrillary structure of this tissue more or less well

preserved, inasmuch as the prisms are less strongly united to one another, while this structure is lost ordinarily by the fusion of the peripheric layers of the prisms of the enamel.

We have had very little opportunity of examining these anomalies; our experience being confined to two cases of congenital patches upon the enamel. But these two teeth presented in the middle of the patches a dark brown color, like the sign of commencing caries; yet the sharp contour of the spots and the well-marked white color left nothing in doubt. They were really congenital patches which were commencing to be affected by caries.

The consistency of the enamel had considerably diminished, the lightest pressure sufficing to reduce to powder the detached fragments. Very rarely a column was seen to separate from the neighboring columns, and then only for a small extent; the contours of the prisms being very distinct, while the oblique striæ were so in only one of the two cases.

The prisms of the enamel were strongly enough united in the two cases, and their cohesion was not diminished, as Mr. Tomes has asserted. In view of the paucity of observations, we will not venture to draw from these facts other conclusions, still less as it is impossible to establish with certainty what ought to be placed to the account of caries and what to congenital alterations of structure.

As for the rest, the predisposition to caries in these congenital anomalies of the enamel is sufficiently proved by the lesser hardness of the parts.

It is remarked also that there is often a coincidence between these anomalies of structure of the enamel and an incomplete development of the dentine, yet the anomalies of structure show themselves less often in the dentine than in the enamel. In most cases there exists in the dentine a great number of interglobular spaces; according to the discovery of M. Magitot, these are seen sometimes in several layers parallel to the surface of the dentine, and spaced in a pretty uniform manner. This anomaly has for cause a defect of development which, in its turn, hinders the calcareous

salts from penetrating certain parts of the tooth in sufficient quantity.

We meet this anomaly more particularly in cases of those more considerable defects of the enamel which go by the name of erosion; while there, where the enamel presents cracks, holes, and furrows, such as we see in "honeycombed" teeth, the dentine very often offers a great resistance.

The causes of the trouble in the development of the tissues of the tooth, as well of the enamel as of the dentine, are of several kinds. Some local affections of the mouth and general maladies of very different nature may cause perturbations in the development of the teeth. Mr. Hutchinson has marked, as a very frequent cause of this anomaly, constitutional syphilis. Nevertheless, it is well proved that many other maladies occasion the same phenomena. Setting aside the greater defects of development, the dental tissues present, in their hardness and chemical composition, varieties which render them more or less fitted to resist external influences. This is easily seen by the difference in the color of the teeth, and by the appearance they present, and it is from these different properties that classifications have been made.

Considering the lack of positive observations upon the subject in question, we can give only our suppositions upon the causes of the varieties of color and of appearance in teeth. The relative quantity of organic substances, and of substances inorganic, seems to be of especial importance. *A priori*, the existence of these varieties of enamel as well as of dentine could not be doubted, and analysis has confirmed the supposition. Nevertheless, the teeth offer us no physical indication by which we are enabled to recognize with certainty one or other variety in their chemical composition. The teeth of different individuals offer in general aspects sufficiently various, but we may say that they diverge in two different directions from that which we have taken as a standard, viz., a white color combined with a moderate transparency of the enamel. The teeth are either much bluer and more transparent than the average, or else yellow and more opaque. There is among them every variety of

different type. The blue and transparent teeth have little power of resistance, while those of a yellow and much less agreeable tinge are distinguished by their very great resistance to the attacks of caries.

It is generally believed that the less power of resistance a tooth has to caries the more organic substance it should possess in proportion to the inorganic; and, in the contrary case, that the inorganic substances should predominate. *A priori*, this theory cannot be admitted. In the experiments which we give farther on concerning the action of acids upon the teeth, it has been demonstrated that the enamel is always the seat of the first changes, while the dentine and the cement are attacked only after some time. It is easy to conceive that a slight diminution of the calcareous salts may become very sensible in the enamel, because the quantity of organic substance is too weak to preserve the form and consistence of the tissue after the subtraction of a portion of the salts; the dentine, on the contrary, preserves, even after the total loss of the calcareous salts, its former shape, and presents a consistency not unlike that of cartilage. Yet are we not permitted to draw from this the conclusion that the richer the dentine or the enamel are in organic matters, the more capable are they of resisting the attacks of caries, inasmuch as many other causes may act at the same time. In spite of this it appears to us probable that the bluish and transparent teeth are relatively less well provided with organic matters, especially in the enamel, than the yellow teeth, which resist better.

Are there still other anomalies of composition, especially in what concerns the quantity of the different salts which influence the predisposition to caries? We as yet know nothing positive thereupon. As for the enamel, the most recent analyses of M. Hoppe have shown that the relative quantities of phosphate and carbonate of lime are sufficiently constant in animals belonging to the most varied species. There are, on the average, three elementary molecules of phosphate of lime for one of lime united with chlorine, fluo-

rine, or carbonic acid.* According to this, at least as regards the enamel, it will be less probable that variations of the proportions of the different salts will ever be proved.

It appears that there exist, also, in the physical hardness of teeth differences which may naturally have a great importance in the predisposition to caries.

II. Influence of Acids upon the Production of Caries of the Teeth.

No one at this day can refuse to believe in the necessity of the action of acids to occasion caries of the teeth. The salts contained in the enamel and in the dentine cannot be dissolved in water; acids are indispensable to work their solution. But it is not at all necessary to employ strong acids for the purpose of separating the carbonic, or even the phosphoric acid from the lime with which they are combined. The calcareous salts of the tooth, as well the carbonate as the phosphate of lime, are dissolved in some acid, even in water which contains carbonic acid, as they are changed into acid salts which water dissolves with sufficient ease. In fact it is acknowledged that the surface of carious teeth very often presents an acid reaction. This reaction is constant upon the contents of carious cavities in which the disease is in active progress. Mr. Spence Bate cites an observation from which we might draw the conclusion that pure water can dissolve the teeth.

A lady had two cases of artificial teeth;† she wore one of these until the teeth were carious, while the other was carefully kept in water. After a period of seven years, wishing to change the worn out case for that which she had preserved in water, she found this latter just as corroded as the one she had worn in her mouth. Does not this case find its explanation in the observations cited by MM. Wedl and Heider, ac-

* Recherches sur la composition de l'email des dents (Virchow's Archiv, xxiv, p. 13).

† Human teeth.

cording to which, at the end of only ten days, fungi had attacked the enamel and the dentine of teeth placed in pure water? A few weeks sufficed to change the tissues to such a point that they were pierced with holes like a sieve. If the action of acids alone could occasion caries of the teeth, it should be easy to demonstrate the phenomena out of the mouth. It is not so. Acids cause, it is true, a portion of the alterations of caries, but its totality differs essentially from the effects which they produce. Several authors have studied the influence of acids, and of different other agents, upon the tissues of the teeth. We will mention especially experiments made in 1843, in North America, by Mr. A. Westcott, with the assistance of Mr. Dalrymple. These authors obtained the following results:

1st. All the mineral, as well as the vegetable acids, act promptly upon the teeth. Acetic and citric acids, for example, in forty-eight hours, corroded the enamel to such a degree as to permit a great portion of it to be scratched away with the nail; malic acid also produced very rapid effects.

2d. The salts whose acids have a greater affinity for lime than for their own bases also acted upon the teeth. The acid tartrate of lime very rapidly destroyed the enamel; grapes, at the end of forty-eight hours, had already acted so strongly that the surface of the enamel presented the appearance of chalk.

3d. Vegetable substances have no action until they ferment, and acetic acid is formed. Sugar, for example, which by itself had no action, produced its effects only in a state of acid fermentation.

4th. Animal substances acted very slowly, and only when they had reached a very advanced stage of putrefaction.

Mr. Allport obtained identical results* in his researches into the action of different acids upon the teeth, making use of very dilute acids, such as are used in medicine. All the mineral acids, as well as citric and acetic acids, in a few hours produced very marked action upon the enamel.

* *Vide* American Journal of Dental Science, April 30th, 1858.

M. Mantegazza engaged in the same investigations, and obtained identical results.* Sugar acted upon the teeth only when, by effect of fermentation, it was partially changed into acetic or lactic acid. Lactic acid, vinegar, strong or diluted, and lemon-juice, acted on the teeth.

We had begun our investigations upon caries of the teeth when the book of M. Magitot appeared.† The results of his experiments which are there given should prove not only that acids and the acid salts act upon the teeth, but also that these are the sole agents of caries, and that the phenomena produced upon the teeth by their action are entirely identical with those of caries of the teeth.

The substances employed by M. Magitot in his experiments were, at first, solutions of a great number of acids, of some acid salts, and, moreover, solutions of sugar, albumen, table-salt, and alum. He submitted teeth to the action of these agents for two years. At the end of this time, the solutions which contained the teeth, in many cases, were covered with thick coatings of mould; the acid solutions had sometimes become neutral, and the teeth were more or less attacked, softened, and destroyed. In a great number of cases the enamel presented a white, earthy appearance. It was chalky and profoundly changed. The dentine was brown or yellow, deprived of its salts, and softened, thus having the aspect of carious dentine.

Moreover, remarkable differences were observed in the action of agents upon the different tissues of the teeth. M. Magitot distinguishes, from the results of his experiments, four categories of substances in relation to their action upon teeth.

These are, according to him,

1st. *Substances which attack alike all the tissues of teeth.* In this category belong the varieties of sugar (but only in a state of fermentation), lactic acid, butyric acid, citric acid,

* Mantegazza sur l'action du sucre et de certains acids sur les dents. Milan, 1862. Trans. in Brit. Jour. of Dent. Sc., 1864, vol. viii, No. 92.

† Etudes et experiences sur la salive considérée comme agent de la carie dentaire. Paris, 1866.

malic acid, carbonic acid, the products of the decomposition of albumen and albuminoid substances.

2d. *Substances which have the particular and exclusive property of destroying the enamel:* Alum, oxalic acid and its acid salts.

3d. *Substances which act exclusively upon the dentine and upon the cement:* Acetic acid, tartaric acid and their acid salts, and tannin.

4th. *Substances which have no action upon the dental tissues*, as common salt and the great majority of other neutral substances which are found in the mouth.

These results do not entirely agree with those of MM. Westcott, Allport, and Mantegazza. In order to verify the experiments of M. Magitot, we submitted a series of teeth to the action of the principal substances used by this author, but we have not been able to convince ourselves that the action of acids alone can produce changes identical with those of caries.

In repeating the experiments of M. Magitot, we have abstained from using the same time. If caries depends upon simple chemical action upon the teeth, it is not necessary to wait years in order to see the effect. When there is a sufficient quantity of the acid solution, we are able to perceive, at the expiration of but few days, a very considerable alteration in the dental tissues, even with the feeble solutions which M. Magitot has used in his experiments. If we leave for years in the liquids the teeth upon which we are experimenting, without assuring ourselves of the quantity of acids which they contain, and without restoring to them the portion of these same acids which they lose by their neutralization in combining with the calcareous salts, it will not be possible to attribute the results obtained to the sole influence of the acids; but it will be necessary also to take account of the decomposition taking place in the organic substance of the tooth, of the putridity of the fermentation, and of the action of the vegetable and animal microscopic growths which are there developed.

The acid reaction of the liquids in which the teeth had

been placed had given place to a neutral one in several of the experiments made by M. Magitot. This proves that in the last portion of time and perhaps for a considerable period the acids had taken no part in the destruction produced.

If the work of caries is, in general, much slower in the mouth, this may depend on the habitual want of a sufficient quantity of acids. Perhaps these exert their action only intermittently, and each time during a rather short period. Our own researches upon the penetration of *leptothrix* into the interior of dental substances, and the observations of MM. Wedl and Heider upon the introduction of fungi into teeth which have been extracted, demonstrate, according to the evidence, the part which may be due to these agents in M. Magitot's experiments.

Nevertheless, as no investigations upon these corroded teeth have been made with the microscope, we have nothing but presumptions. The resemblance to caries which has been found in these experiments relates therefore only to the diminution of the consistency of the enamel, which became tender and friable as in caries, with a brown or yellow color, and to a more or less advanced softening of the dentine. This softening sometimes reached a very high degree.

But these external resemblances do not prove that this was veritable caries, and, even if, by microscopical research, symptoms had been found identical with those of caries, it would not then be demonstrated that they are due exclusively to the action of acids.

It follows that the results of our experiments are not completely accordant with those of M. Magitot, while they confirm precisely those obtained by MM. Westcott, Allport, and Mantegazza.

We have found that all substances capable of changing the dental tissues produce, at first, a deterioration of the enamel, which is soon followed by that of the dentine. The enamel, which, in its normal state, is transparent, becomes white and opaque, milky, and, in a more advanced state, chalky. At the beginning, and, above all, when the enamel

is very hard, there is sometimes seen only a whitish color and the disappearance of the transparency. The surface may, in such cases, remain polished and shining; later, it becomes rough and uneven, and the enamel thus acquires an earthen, chalky appearance. The softening increases little by little, and gains in depth; so that in a short time we can scratch away the enamel with the nail, or break it off in bits. In using certain acids, which form salts difficult of solution, we see the enamel and also the root covered with innumerable and very beautiful crystals.

When the enamel presents the first degree of alteration, the appearance of the dentine and also that of the cement is normal, and its hardness has not as yet undergone any change; we recognize the alteration which follows by a more transparent look to the roots, which, at first, can be cut with a knife at the surface; soon after we can cut them more deeply; at a more advanced period we can even bend them. It is true that sound dentine can also be slightly cut with a knife, but, in doubtful cases, it has always been our habit to compare the dentine submitted to the action of acids with normal dentine.

In proof of our statements we give here a few extracts from our experiments.

1st. Tartaric Acid.

(*a.*) SOLUTION $\frac{1}{10}$ IN 100.

At the end of two days the enamel was seen to be covered with minute crystals; these removed, the enamel had lost its brilliancy and taken a white, earthy aspect. No change remarked at the root.

At the end of eight days the alteration of the enamel was increased; with a knife slices could be taken from the surface.

At the end of a fortnight the alteration of the enamel had made new progress, while the root was only slightly softened at the surface.

(*b*) GRAPES.

Some teeth were placed among crushed grapes whose juice was rather acid.

After forty-four hours the surface of the enamel was very rough and covered with numerous crystals. Upon brushing these away, the enamel appeared uneven and slightly chalky; its brilliancy was gone. The root was likewise slightly covered with minute crystals; it had not yet undergone noticeable change.

At the end of eleven days the experiment was ended. The divided enamel presented, throughout its whole thickness, an earthy, white appearance, and was porous; the root was scarcely changed.

2d. Acetic Acid.

SOLUTION $\frac{1}{10}$ IN 100.

At the end of ten days the enamel was found to have on its anterior surface an earthy, white appearance; it could be removed with the finger-nail; while, on the posterior surface, it remained almost in its normal state. The surface of the root could be cut with a knife.

At the end of seventeen days the enamel could everywhere be broken off in great pieces; the subjacent dentine was also decalcified. With a knife the root could be easily cut.

3d. Oxalic Acid.

SOLUTION $\frac{1}{10}$ IN 100.

After seven days the bottom of the glass was covered with a thick layer of white powder composed of minute crystals of oxalate of lime. The enamel, of an earthy white, could be removed with the finger-nail; a part of the crown had preserved its polish. The root did not seem altered.

At the end of fourteen days the enamel was everywhere of an earthy white, and could be easily removed with the nail. The root could be cut with a knife, especially at the ends, with greater ease than in its normal state.

4th. Alum.

SOLUTION 1 IN 100.

At the end of two days no trace of change.

After six days the polish at the lower part of the enamel was seen to be diminished, and the enamel was covered at the same part with a light earthy layer which was easily removed. The root appeared to remain intact.

At the end of twenty days the enamel could be easily removed with the nail; no other changes. The root could be cut more readily than in the normal state.

5th. Lactic Acid.

(*a.*) SOLUTION $\frac{1}{10}$ IN 100.

At the end of ten days it was impossible to perceive any alteration in one of the teeth, a very strong molar; in another tooth the enamel was everywhere whitened, part roughened, part still polished; everywhere it was easily removed. The root was not sensibly altered.

After seventeen days, on the first tooth was seen, at the extremity of the crown, a slight milky color without loss of polish. At this part, with a knife, small shavings could be removed. Root intact. On the second tooth the alteration of the enamel had increased; its root could be cut with a knife more easily than in its normal state.

(*b.*) SOLUTION 1 IN 100.

After two days the enamel was earthy and without polish; the root was normal.

At the end of thirteen days the enamel could be everywhere removed with the nail. The root was decalcified on the surface; it was easily cut with a knife, but only to a slight depth.

It appeared to us superfluous to prolong further our experiments; we usually interrupted them after having become well satisfied that the dentine was beginning to be decalcified;

any ulterior action possessed no interest for us, and we cared little to know if it was possible to completely decalcify the teeth or not by the aid of different concentrations of acids. We have been able to convince ourselves, in some of our experiments in which the teeth have remained subjected to the action of acids for a long time, that it is possible even with very weak acid solutions to decalcify teeth pretty completely.

It results, from the experiments which have just been related, that tartaric and acetic acids, even very weak, produce upon the enamel the same changes as other, especially the lactic and oxalic acids, while M. Magitot asserts that tartaric and acetic acids attack only the dentine and never the enamel. We know not how M. Magitot has obtained such opposite results; we content ourselves with remarking that he also noticed that tartaric acid had produced a layer of little crystals upon the surface of the enamel, and that they adhered to it sometimes very strongly. Yet, according to him, beneath these crystals the enamel was found in a normal state. We, on the contrary, have noticed, after having removed these crystals, that the surface was left uneven and roughened; the enamel was transformed to an earthy mass even to a great depth. Perhaps this difference of results can be explained by the supposition that in the experiments of M. Magitot, although there may have been no loss of substance in the enamel, yet it may have been transformed into a chalky mass. On the other hand, it is possible that the differences in the consistency and perhaps also in the chemical composition of the enamel, from which results a different resistance to the action of acids, have acted in the manner described in our experiment No. 5.

Our experiments are in harmony with those of Mr. Westcott, of Mr. Allport, and of M. Mantegazza, who found that all the vegetable acids, without distinction, attacked the enamel of the teeth.

Our experiments do not permit us to admit, as M. Magitot asserts, that oxalic acid and alum attack neither the cement nor the dentine. It is true that the diminution of the hardness of the dentine begins always later than the first altera-

tion of the enamel, but all the acids produce the same effect; so we stopped pushing farther our experiments, with the end of decalcifying more completely the dentine. It would be easy to show the diminution of the hardness of the root of the tooth by the action of oxalic acid, or of a solution of alum; nevertheless, it appeared to us that oxalic acid, tartaric acid, and solutions of alum, attack the dentine a little more slowly than does acetic acid, for example; lactic acid much weakened, acts also very slowly.

The specific action which M. Magitot has attributed to certain substances upon the dental tissues must therefore have for cause some fortuitous circumstance, inasmuch as subsequent experiments, made in the same manner, entirely fail to confirm it.

As for the action of sugar, all experiments result in showing that in its normal state it never attacks the teeth; it acts only on passing into the state of acid fermentation. We have obtained identical results. The most decisive experiments upon this point have been made by M. Magitot. He boiled a solution of sugar, deposited the teeth in it, and closed the neck of the bottle hermetically, by heating it to a white heat, drawing out and twisting it. No fermentation was then possible, and at the expiration of two years the teeth were found entirely untouched.

The different action of acids upon the different tissues of the teeth is explained by the presence of variable proportions of organic substances which enter into the composition of the enamel, the dentine, and the cement.

In the enamel, where the organic substances enter only in the proportion of some hundredths, the least diminution of the salts should produce great disorder in the molecular composition, and, consequently, upon the physical properties of this tissue; while a slight loss of inorganic substance would not be easily perceived in the dentine, for the organic matters which it contains would suffice to maintain its consistence.

The enamel, stripped of its calcareous salts, possesses only a minute quantity of organic elements, which, placed under

the microscope, present for only an instant the enamel structure; they are seen promptly to dissolve. The dentine, deprived of its salts, has, on the contrary, the consistence of cartilage, and entirely keeps the form of undecalcified dentine.

The acids produce upon the enamel phenomena which are likewise found in caries of the enamel; thus, these latter may be explained by the action of acids. In both cases the enamel, being deprived of a portion of its salts, becomes porous, opaque, and softer.

Out of the mouth the action of acids is always perceived first upon the enamel. It remains to be ascertained if the dissolution of the calcareous salts of the dentine does not take place at the same time as that of the enamel, although not manifesting itself to the observer until later. We are inclined to think so, inasmuch as we have no reason for admitting that the salts of the dentine are less soluble than those of the enamel. As for the rest, there are in the hardness of the enamel and of the dentine differences which predispose them to be more or less rapidly attacked, and whose influence upon the production of caries we have long appreciated.

As to the utility of all these experiments, they teach us that sugar and sugared liquids, placed in circumstances favorable to acid fermentation, are able to exercise by this alteration an injurious action upon the teeth. In the mouth are found all conditions favorable to this fermentation, therefore all solutions of sugar are capable of acting in precisely the same manner as acids.

To sugar is very generally attributed an injurious action upon the teeth. That this opinion is well founded is confirmed by the oft-repeated observation that caries is especially common and intense with persons of certain professions, such as confectioners and cooks, who eat or taste many sweets, and who, moreover, take sugar into the mouth in the form of dust while pulverizing or sifting it.

It is true that other observations would seem to prove the contrary. The blacks of the East Indies who eat enormous quantities of sugar are remarkable for very beautiful and

very sound teeth. M. Mantegazza confirms this fact by his own experience, and adds further that the Indians, who eat constantly the sugar cane and other products of their country rich in sugar, have likewise excellent teeth. Nevertheless, M. Mantegazza does not attach much weight to these observations; he thinks that these populations differ from us in their whole organization too much for us to be justified in drawing from them conclusions applicable to civilized people. Yet we may deduce from these facts the consequence that teeth well developed, hard, and strong, will not suffer from even the freest use of sugared aliments, while those of a less dense structure may suffer from it considerably.

It would seem to result from all this that the Europeans, and the races sprung from them, as for example, the North Americans, have teeth less perfectly developed, and less resistant than the negroes and the natives of America. From this we are not permitted to attribute the great amount of caries of the teeth which is found among the Europeans and North Americans solely to their more refined manner of living, and to the use of substances little favorable, and even injurious to the teeth; but we are compelled to admit that, with them, the disposition and the development of the teeth are less perfect.

It is impossible for us here to enlarge further upon the causes of these singular phenomena, which refer evidently to the characteristic development of the races. We must, however, refer in this connection to the remarkable differences in frequency of caries in the different parts of France; M. Magitot has given special attention to this point.*

The experiments which we have made upon the action of acids upon teeth have led us on to a series of other observations which have reference to the origin of caries of the teeth.

Some observations establish that, at the end of a somewhat prolonged course of grape cure, patients have perceived that their teeth have become affected. Their surfaces have become rough, a superficial layer of enamel has been destroyed,

* Traité de la carie dentaire, p. 61–66.

and, in some cases, true caries has been developed. We can confirm from our own experience the fact of the roughness of the teeth, and the production of caries as a result of courses of grape cure. In one case, where the teeth were extraordinarily hard and dense, and where the cure had been interrupted at the moment when the teeth began to grow rough, there was no caries, and the roughness gradually disappeared. In other cases, on the contrary, a greater or less loss of enamel was observed, and caries appeared. The roughness is, without doubt, the consequence of the alteration of the superficial layers of the enamel, and the deposit of very minute crystals of tartrate of lime, as we have seen produced in our experiments with tartaric acid and the juice of the grape. It will therefore be well to caution those whose teeth are of poor quality against the use of such cures, except with the utmost precaution, forewarning them that the juice of the grape may injure their teeth.

After having established by our experiments that acids of the most various kinds attack the teeth, it behooves us to inquire what are the acids which take part in the caries of the teeth, and how they get into the mouth. We know that acids are always introduced into the mouth with our food and drink: acetic acid is associated with great numbers of viands as a condiment; malic, citric, and tartaric acids are found in different kinds of fruits, and in the drinks which are made from them; oxalic acid is found in certain plants; lactic acid in sour milk, and so on. We have, moreover, pharmaceutic remedies which contain mineral acids and their acid ethers; then tannin, some salts, alum, for instance, are able to attack the teeth. All these substances may easily bring on caries or contribute to hasten its progress; but we think that the acids formed in the mouth as the result of decomposition, or those which are found in the buccal secretions, play in this matter a much more important part. The liquid which exists in the buccal cavity is composed, as is well known, of a mixture of the secretions of the salivary glands and of the mucous follicles of the mouth. The secretions of these different glands are almost all, at

least in the normal state, neutral or alkaline; the liquids, then, which are in the mouth, cannot be acid, not taking into consideration the acids which are directly introduced either by an anomaly in the secretion, or else in consequence of fermentation caused by particles of food remaining in the mouth.

Among the secretions of the salivary glands, that of the parotid alone may be feebly acid; that of the submaxillary and sublingual glands is, on the contrary, constantly alkaline. This fact has been proved by the aid of sounds introduced into the efferent canals of these glands. The secretion of the parotid is sometimes acid when first collected; but this reaction passes promptly to the neutral state, or to one slightly alkaline, when the liquid loses the clearness which it possessed at first. This acid reaction arises, according to M. Œhl,* from the carbonic acid absorbed in the liquid, which holds in solution the carbonate of lime with which the liquid secreted by the parotid is abundantly provided. When the carbonic acid disappears, the acid reaction ceases to take place and the carbonate of lime which it holds in solution is precipitated.

This circumstance explains the formation of the tartar upon the teeth. The fact that this sometimes contains a large quantity of phosphate of lime at the same time with the carbonate is not in contradiction with this explanation, inasmuch as the carbonic acid may hold phosphate as well as carbonate of lime in solution. The precipitates of the calcareous salts inclose numerous elements of *leptothrix* and of other products which are met with in the mucosities of the mouth, such as epithelial cells, leucocytes, &c., as we have hereinbefore shown.

The numerous minute follicles of the buccal cavity secrete a liquid which goes by the ordinary name of buccal mucus, and which, very probably, in its properties resembles the secretions of the submaxillary and sublingual glands. Ac-

* La saliva humana, &c. Pavia, 1864. *Vide* Meissner's Jahresber. (Meissner's Annalen f. rat. Med., xxv Bd. 2 H., S. 242.)

cording to their seats they are called follicles of the lips, of the cheeks, of the palate, of the tongue. Their structure is perfectly identical with that of the salivary glands, and their secretions contain, like those of the submaxillary and sublingual glands, a great quantity of mucus which comes from the epithelial cells of the follicles, while the secretion of the parotid is very liquid and contains no mucus.

The particular reaction of the mucous secretion furnished by the buccal cavity naturally cannot be established in a direct manner in man; nevertheless, from the fact that the mixture of all the secretions of the mouth, which constitutes the ordinary saliva, has, as a rule, an alkaline or neutral reaction, we may conclude that the secretion of the mucous follicles of the mouth is in like manner neutral or alkaline. This has been proved directly by an experiment made on a dog by M. Cl. Bernard. After having made a section of all the salivary conduits, he found that the liquids contained in the mouth, which clearly could no longer be mixed with secretions supplied by the salivary glands, were alkaline; the secretion of the mucous follicles, at least of dogs, must then be alkaline.

It has also been asserted that the mucous membrane of the buccal cavity can, independently of the mucous follicles which it contains, give out an acid secretion, especially when irritated.

Mr. Tomes shares this opinion, which he rests principally on the fact that cotton placed between the teeth, in such a manner as to irritate the gum, evidently favors the progress of the caries which exists at any point. But these facts can be refuted by considering that the cotton, as a porous substance, must necessarily favor the work of decomposition and of fermentation which is going on at this spot. It has not as yet been shown directly, and we may say that it is not very probable, that the mucous membrane of the mouth, aside from the secretions of the glands which it contains, secretes a fluid peculiar to itself in any great abundance.

It is, nevertheless, a fact which is commonly observed, that the interior of the mouth, but above all, the surface of

the teeth and gums, shows an acid reaction. This reaction may, *a priori*, be attributed to two causes: first, to the abnormal nature of the secretions of the mouth, and, second, to an acid fermentation of particles of food.

As for the reaction of the liquids of the mouth, we have already remarked that the secretions of the parotid possess, in most cases, an acid reaction; hence it may be presumed that, in given circumstances, the acidity of the saliva may be sufficiently increased for the teeth to be affected by it. The momentary acid reaction which the secretion of the parotid possesses in the normal state, and which is caused by carbonic acid, can naturally have no injurious influence upon the teeth, seeing that it is even powerless to prevent the tartar from precipitating from it. If this acid saliva were able to dissolve a greater quantity of calcareous salts than that which it already holds in solution, we should never see any portion of these salts form a precipitate; but, as all saliva deposits more or less tartar, it is very improbable that it can, in general, attack the teeth.

It is true that cases are found, where the caries has a very rapid progress, in which there is almost a total absence of deposits of tartar; but we generally find in such cases a diminution of the salivary secretion, which explains the absence of tartar. The acids which form in the mouth are no longer neutralized and diluted by the saliva; therefore they have a greater facility for attacking the teeth. We believe, on the contrary, that the saliva protects the teeth against the action of acids, from whence arises the particular immunity which the canines and incisors of the lower jaw seem to possess; teeth which are constantly bathed in saliva. Those persons who secrete but a small quantity of saliva have predispositions to caries of the teeth; a particular predisposition to this affection springs, in like manner, from the diminution of the saliva which takes place during the course of certain maladies.

The action of tobacco-smoke, which favors the salivary secretion, appears to be salutary; in no case does it ever

exert an injurious effect upon the teeth, although, in time, it gives them a color far from agreeable.

An acid reaction has often been attributed to the secretion of the mucous follicles of the buccal cavity. This opinion is based upon a layer of mucus situated upon the surface of the interior of the mouth, and, especially, upon the gums and teeth, which has an acid reaction, and in which are found the elements of *leptothrix*, the epithelial cells of the mouth, leucocytes, &c. It appears, nevertheless, that the acid reaction has nothing in common with the follicular secretion; it should be attributed to the acid fermentation which takes place in this secretion, or in the saliva mixed with starchy or sugary liquids. It is when fasting that the acid reaction is the most marked; that is to say, at the moment when the salivary secretion is reduced to its minimum, so that the acids which form are not at once neutralized and diluted. M. Œhl, nevertheless, found that, even when fasting, no acid reaction took place when the mouth had been scrupulously rinsed after eating.

M. Œhl has made a comparison between the changes which take place in pure saliva and that mixed with alimentary débris, when exposed to the air. He collected one portion of saliva after the ingestion of amylaceous substances, and another after the mouth had been thoroughly rinsed. The two liquids destined for the experiment were then filtered, and left to themselves. The former, which contained starch, reduced sulphate of copper, proving that a portion of the starch had been converted into sugar. It remained several days in a state of acid fermentation before passing to the state of putrefaction with alkaline reaction. In the second liquid, which contained only pure saliva, there was no acid reaction, but on adding starch or sugar to this saliva, primitively pure, in like manner as in the former, an acid fermentation was seen to take place. Nevertheless, the presence of the saliva was necessary to produce this acid fermentation, inasmuch as a solution of starch paste, or of sugar, free from all other mixture, and placed in the same conditions, did not become acid in the same space of time. Where sugar or

starch was held in the mouth, when its reaction was alkaline, an acid reaction was found at the end of from twenty to forty minutes, and even sooner, when grape sugar was used. The acid reaction of the saliva which we meet in persons afflicted with diabetes is, according to M. Œhl, due to the same cause, inasmuch as sugar is found not only in the urine of such persons, but in nearly all the secretions, and especially in the saliva. The secretion of the parotid was able in the first experiments to give by itself an acid reaction, which was not the case with the saliva coming from the submaxillary glands, but was from a mixture of the two, especially when mixed with mucus. The acid arising from this fermentation is, according to M. Œhl, probably the lactic.

It results from these experiments that the saliva of man, when starch or sugar is mixed with it, can produce an acid fermentation, and that an identical fermentation can take place in the mouth. The possibility of the acid fermentation of a solution of starch is subordinated to the property possessed by the saliva of changing starch into sugar, which, in contact with a ferment, undergoes an acid fermentation. It is now acknowledged that, in man, it is not only the mixture of the different secretions of the mouth, but also the isolated secretion of the parotid and that of the submaxillary glands which are able to change starch into sugar.

If, according to this, the acid reaction of the mouth should be attributed chiefly to the presence of alimentary débris, we should always take into consideration the relative quantity of saliva and of mucus. Besides the influence exercised by the quantity of the saliva, whose action is to dilute and to neutralize the acids, a greater quantity of mucus may also possess importance, inasmuch as, by its viscosity, it hinders the too rapid mixture with the saliva, a fact which explains the possibility of finding locally, at the surface of the teeth, for example, acids inclosed in a thick mucus; whilst, in other portions of the buccal cavity, a neutral reaction can be found, or even one slightly alkaline.

In opposition to our opinion, which consists in asserting that the acid reaction is caused chiefly by alimentary débris

in the mouth, it may be objected that during the course of certain acute diseases, and especially in typhoid fever, the teeth are strongly attacked by caries, and that, in spite of the diet habitually prescribed, there is an increase of acidity. It must, nevertheless, be considered that the diet is never absolute, and that constantly sugar, and very often acids, are introduced into the mouth by means of medicines; the amount of this sort of drinks is indeed considerable, on account of the thirst from which patients suffer. A cause, in like manner very important in the production of an acid fermentation in these maladies, is the diminution of the salivary secretions, which are more concentrated, and contain more mucus, so that the elements necessary to fermentation are not wanting; whilst the acids which are formed, on account of the small quantity of saliva, cannot be properly diluted or neutralized.

The lack of mastication must at the same time favor in certain parts of the buccal cavity the accumulation of viscous mucus in a state of acid fermentation. Under the influence of like causes there is established in the mouth an enormous mass of elements of *leptothrix*, which form upon the tongue and teeth a portion of the sooty layer, whitish at first, afterwards dry and brown, which is found there.

The most various irritations of the buccal cavity, and generally all the acute or chronic affections of the digestive canal, as well as the acute idiopathic maladies, exercise an influence upon the production of caries. Likewise, in these maladies, the mouth contains a greater quantity of this viscous coating, which gives an acid reaction. It appears that, in these cases, the mucus mixes in considerable proportions with the secretions of the buccal cavity, whilst the quantity of saliva is not positively diminished. But it is just the great viscosity of the mucus which hinders the mingling of the liquids in the mouth, and favors the production of partial fermentation. We have already called attention to the acids which come directly from the stomach to the mouth in cases of dyspepsia. We have likewise had occasion to remark the frequent cases of caries of the teeth which are

met with in persons afflicted with diabetes; they are attributed to the sugary matters which the saliva contains, and which are changed, according to M. Œhl, into lactic acid.

Nearly all observers have remarked the frequency of caries of the teeth in pregnant females. This is sufficiently accounted for by the troubles which they experience with their digestion, which are accompanied by the formation of acids in the mouth during the continuance of this condition. I think it is not necessary to find here any analogy, as many observers have done, with the *osteomalacia*, sometimes met with in pregnant women. There are seen, it is true, in pregnant women, cases of *osteomalacia*, which must be caused by their state of pregnancy. Cases of cure of this malady have been recorded where it had affected the pelvis, and which recurred again during another pregnancy, to be again cured after delivery. But aside from the extreme rarity of these cases it is not proved, it is not even probable, that the calcareous salts of the dentine can be taken up again in the same manner as the salts of the bony tissue in general; we must therefore refuse to admit such an explanation.

If we recapitulate, we shall find in the work of fermentation which takes place in the mouth a continual source of acidity. This acidity, by its action on the teeth, without doubt acts with much greater energy than the acids formed transiently by the alimentary débris, or by any other substance introduced into the mouth. The *rôle* of the saliva is here to change into sugar the starch contained in the food; moreover, the sugar contains fermentable substances which produce an acid reaction. Nevertheless, the saliva dilutes and neutralizes the acids, when it exists in sufficient quantity, and thus hinders their action on the teeth. We cannot, then, justify the assertion of M. Magitot that the saliva is the veritable agent of caries of the teeth. He contradicts himself, adding, in the same phrase, that the saliva cannot produce this effect when it retains its original composition, but only in consequence of certain modifications occasioned by the presence of injurious substances formed spontaneously, or introduced from without. It appears, then, evident that

it is not the saliva, but rather these injurious substances which should be considered as the agents of caries of the teeth.

As far as we know, the veritable nature of the acids found in the mouth has not yet been demonstrated by any direct experiment; nevertheless, it is generally thought to be lactic acid, and this opinion has the greatest probabilities in its favor.

As a general rule, it is lactic acid which is produced by the fermentation of sugared liquids and others, when there are present at the same time albuminoid substances. This fermentation is particularly favored by the presence of the carbonate of lime, which neutralizes the acids gradually as they are formed; whilst the fermentation itself is hindered by a little more considerable abundance of acids.

Now all these conditions are fulfilled in the buccal cavity; the saliva and the mucus contain albumen, and carbonate of lime exists in great quantity in tartar and the dental tissues. We know not whether or not there are formed still other acids. We might expect to find in the mouth the fungi which, according to M. Pasteur, should accompany and produce the lactic fermentation, "ferment de l'acide lactique de Pasteur." But the opinions of authors upon the ferment of lactic acid differ so greatly that it is impossible for us to attribute any great value to the presence of this ferment in the mouth. According to M. Pasteur the elements of the ferment of lactic acid are molecular corpuscles, very minute, which present a very marked Brunonian movement whose dimensions he does not state on account of their extreme minuteness. In the work of one of his pupils, M. Van Tieghem, upon the fermentation of urine, there is a figure of one of these fungi in which these latter are contracted in the middle and larger than the spores of the urine ferment which are pictured by their side, and have a diameter .0015 millimetre. The form of these fungi, according to M. Van Tieghem, is identical with that of the *mycoderma aceti* of M. Pasteur, of which the diameter is likewise .0015 millimetre. This figure, then, does not at all agree with those given by M. Pasteur.

The observations of M. Hallier upon the ferment of lactic acid (*oidium lactis*, Fresenius) are entirely different from those of M. Pasteur. According to him the elements of this ferment consist of great cells of a rounded quadrangular form; they should be constantly found in the acid fermentation of milk, and, moreover, upon all substances in a state of acid fermentation.

We have ourselves found, in milk soured at a low temperature, minute corpuscles endowed with power of very rapid motion, which appeared to us to be identical with those described by M. Pasteur. We have also encountered elements of this kind in saliva containing sugary matters, which had passed into a state of fermentation; united, these elements presented the appearance of granular masses of *leptothrix*, especially near the margins of the preparation, where, in consequence of the evaporation of the liquid portions, their movements had been arrested. Nevertheless, in no one of these cases have we been able to obtain a reaction either with iodine or with the acids.

We greatly regret that there are so few methods of distinguishing with exactness the different species of fungi, and we cannot set ourselves the task of undertaking researches so extensive, and demanding so much time. We confine ourselves in consequence to presenting some observations upon the possible coincidence of the acid fermentation in the mouth with the presence of a development of fungi.

Besides the presence of a great quantity of *leptothrix*, we see in the mouth but a very small number of spores and filaments of a fungus which bears a resemblance to *oidium*. But the masses of *leptothrix* are so predominant that we are disposed to believe in their participation. If, in general, the fungi play a *rôle* in the acid fermentation of the mouth, which is not proved, we are inclined to attribute it to the *leptothrix*. This opinion is founded upon the resemblance which the corpuscles in movement during the fermentation of the saliva and of milk present to the lactic acid ferment of M. Pasteur, and to the masses of *leptothrix* which are really formed in the mouth.

The absence of the violet reaction, so characteristic, which we find in the former case, depends perhaps upon a different degree of development.

III. Influence of Leptothrix upon the Production of Caries of the Teeth.

We have already several times remarked that the action of acids alone does not account for all the phenomena which appear in caries of the teeth. It is true that acids, even very much diluted, can attack the dental tissues; but we find, in their mode of action, differences which distinguish them from the phenomena and from the progress of dental caries. The acids attack first the enamel and rapidly change it to a chalky mass; later only, their action is felt in a marked manner upon the dentine, which becomes more transparent and, in fine, as if cartilaginous, by the very slow but progressive loss of its calcareous salts.

Caries, on the contrary, proceeds slowly in the enamel; it is much swifter in the dentine, where it proceeds promptly along the canaliculi. This difference of progress must be attributed to the participation of the fungi in the work of the caries. The elements of the fungus glide easily into the interior of the canaliculi, which they dilate, and thus favor the passage of the acids into the deeper parts; these same elements cannot penetrate a compact enamel, or at least they enter more slowly, and only when the elements which form it have been greatly changed by the action of acids.

Leptothrix is found almost constantly in the buccal cavity, if great care is not taken to rinse the mouth frequently. Mr. Bowditch, in examining forty persons of different professions, and living different kinds of life, found in almost all vegetable and animal parasites. Those only were found to be free who cleaned their teeth several times a day, and at least once with soap. The parasites were numerous in proportion to the neglect of cleanliness. The means ordinarily employed to clean the teeth had no effect upon these parasites, whilst soap appeared to destroy them.

M. Kölliker, out of twenty to thirty young and well persons, found hardly one the papillæ of whose tongue was free from a grayish and granular coating; he more rarely met with filaments of the fungus. It is true that regard must be had to the hour of the day at which the examinations were made; it is natural that all these matters should always be more abundant when the individual is fasting.

But, while in ordinary circumstances, the fungi are found only at the surface of the buccal cavity, they are seen to penetrate into the interior of teeth during the progress of caries. For them to be able to penetrate thus it is necessary that the teeth be in a suitable condition; the enamel and the dentine must have lost their density by the action of acids.

It seems that the fungi are not able to penetrate an enamel of normal consistency. The dentine itself, in its normal condition of density, offers great difficulties to their entrance, and we are not yet sure that the *leptothrix* could triumph over this resistance. We do not speak here of the greenish deposit found upon teeth, which differs from caries, and upon which we have not yet sufficiently experimented. It may happen that, under favor of this deposit, fungi may penetrate into the superficial layers of the enamel, which does not appear to be the case in ordinary caries. Habitually the teeth expose to the action of injurious agents only their crowns covered with enamel, and this protects them from the attacks of the fungus. We cannot decide, at present, if the *leptothrix* is able to penetrate sound dentine, when from any abnormal circumstance it happens to be denuded. But if the enamel or the dentine are become less resistant at any point through the action of acids; or if, at the surface of the dentine, a loss of substance has occurred, then the elements of the fungus can pass into the interior of the dental tissues, and produce by their extension, especially in the dentine, effects of softening and destruction much more rapid than the action of acids alone is able to accomplish.

The participation of the fungus is constant in the progress of caries which has reached this stage. As soon as a loss of

substance can be shown there is found the presence of the fungus, so that the question whether or no the acids alone could produce ravages more considerable is without importance. But in the early stage, when the surface of the tooth is still polished and intact, we have never been able to prove the presence of the fungus; it appears, therefore, that at this stage of the malady, which constitutes the dry caries, properly so called, all the disorders must be attributed to the sole action of acids.

The development of the fungus seems to be favored by a neutral or slightly acid medium, whilst it cannot flourish in a strongly alkaline liquid. We have already called attention to the observation of Dr. Bowditch, who has seen the parasites disappear upon rinsing the mouth with a solution of soap. M. A. Vogel found that the fungus, *oidium albicans*, continued to develop in pure water, in solutions of salts without alkaline reaction, and especially in solutions of sugar; whilst no proliferation could take place in solutions slightly alkaline. These observations, to judge of them by analogy, seem likewise to prove that alkaline liquids may exercise a destructive action upon the *leptothrix*.

IV. Therapeutic Conclusions.

It is not without importance to cast an eye, before concluding, upon the therapeutic conclusions which should be drawn from the results which we have reached, and to see if they are in accord with the experience of practitioners.

Before all, as regards the prophylactic indications, it can be said that we should seek to neutralize the acids which form in the mouth, and to prevent all work of fermentation and of development of fungi by proper care for cleanliness. Teeth well formed may be spared by caries in spite of the greatest negligence; but we should take the greater care of our teeth in proportion as they are badly developed or irregularly arranged. With great care even malformed teeth may be preserved from caries. In cleaning the teeth such brushes should be used as are not too hard, and which, by a slight

pressure, can be made to enter the spaces between the teeth. We may advise, as useful for this purpose, the employment of soap, which, by imparting a slightly alkaline quality to the water, neutralizes the acids and hinders the development of fungi.*

In many cases the soap does not suffice to remove entirely the deposit formed upon the teeth; in such case there should be added to it powders which act mechanically, but care should be taken that they are not too gritty; the disagreeable taste of soap may be easily corrected.

We can also recommend the permanganate of potassa dissolved in water as an excellent mouth wash, inasmuch as this remedy is a very excellent antiseptic, and at the same time the best means of preventing fermentation; this water exercises a beneficial action upon the mucous membrane of the mouth.

As regards the artificial treatment of caries our observations are at every point in accordance with the experiments made up to this time. In filling the teeth the air and liquids are hindered from penetrating, and all work of fermentation, and all development of fungi, become impossible.

There has appeared lately in the *Archives of Virchow*, vol. xli, an article by Dr. Hertz upon "Dental Caries." This author, having no knowledge of our experiments, has not discussed our opinions, although his *memoire* appeared some time after ours. In a note added to the end of his work he wrongly accuses us of rejecting all vital action of the dentine in the production of caries.

As for the rest, the opinions of Hertz are nearly in agreement with those of Neumann. He asserts that he has never observed alteration of dentinal fibrils in natural teeth of substitution. We maintain the correctness of our observations on this subject. It only remains to determine if the alterations we have described are constant, or if they are wanting in certain cases.

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* *Vide* J. B. Rottenstein. Des soins à donner aux dents. Frankfort-sur-le-Maine, 1857.

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EXPLANATION OF THE PLATES.

PLATE I.

FIG. 1. (Magnified three diameters.)

Longitudinal section of a carious bicuspid. The section is slightly slanted across a large carious cavity; upon the left side of the crown a cone of a dark color is seen in the dentine altered by caries; this cone extends in the direction of the dentinal canals from the surface even to the pulp-cavity, and presents a radiated striation which corresponds to these canals. Upon the surface of the section the loss of substance extends only upon the enamel, whilst upon the neighboring parts it penetrates deeply into the interior of the dentine. Upon the masticating surface of the enamel are seen two fissures.

FIG. 2. (Magnified three diameters.)

A longitudinal section of a canine tooth with commencing caries. In the centre of the crown is a small carious point in a depression of the enamel; the caries has not as yet attacked more than a superficial layer of the enamel. A similar point exists at the left side of the crown, also without loss of substance, and it is from this point that the caries has extended across the whole thickness of the enamel, and nearly across the whole thickness of the dentine to the neighborhood of the pulp-cavity.

The outermost layers of the dentine are of a darker color than the deepest layers of the enamel, the color diminishing in both from the surface inwards. There are, moreover, three small carious cavities which reach to the surface of the dentine; also cones of carious dentine are seen to start from these cavities and point to the pulp-cavity; one of these cavities exists at the right side of the crown, the two others are found at the neck of the tooth.

FIG. 3. (Magnified three diameters.)

Section of a human molar with caries commencing. In the middle of the crown a loss of substance in the enamel (the enamel has been broken away at the sides in the process of preparation); in the dentine a cone of a clear color altered by caries; this clear color is due to the transparency of the

tissue; the brownish color cannot be perceived on account of the thinness of the specimen.

FIG. 4.

A fragment of this same section magnified one hundred diameters. A very thin layer of enamel is seen on a level with the loss of substance; the most superficial layers are very transparent in consequence of the disappearance of the calcareous salts. It is seen, also, that the surface is irregular and covered with fissures and cracks. The layer of *leptothrix* is not preserved at the surface, but there exist at one point masses of granular *leptothrix* which have penetrated the dentine across a fissure of the enamel. The outer layers of dentine are dark and the canals more difficult to distinguish; in the deeper layers are found little deposits of calcareous salts in the canals and interglobular spaces.

PLATE II.

FIG. 1. (Magnified one hundred times.)

Section of the surface of a carious cavity. The dentine is reduced to fragments enveloped with *leptothrix*. On the free surface delicate filaments of the fungus are seen crossing the granular masses.

FIG. 2. (Magnified one hundred times.)

The decomposition of the dentine has made still greater progress. The débris are much smaller and less voluminous than the masses of *leptothrix* which surround them.

FIG. 3. (Magnified one hundred times.)

Transverse section made at the surface of a cavity across the carious dentine. The dentinal canals are greatly thickened (which is difficult to observe in the longitudinal section of Figs. 1 and 2); at the surface is a thick layer of very fine filaments of *leptothrix*.

FIG. 4. (Magnified two hundred and fifty times.)

Transverse section of an artificial human tooth attacked by caries. The changes are identical with those of the natural teeth. The canals are more or less dilated; some are considerably so and have thickened walls, that which could not be distinguished upon those of the canals which were the most thickened.

Plate II.

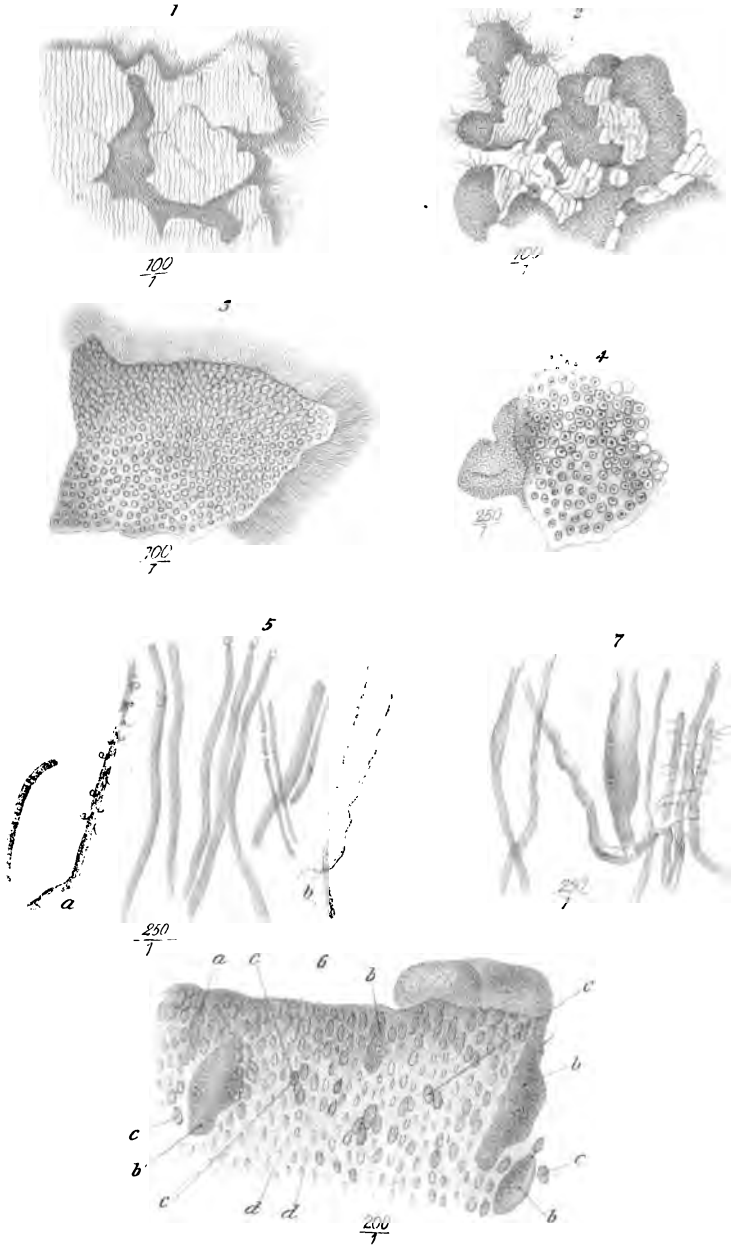

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FIG. 5. (Magnified two hundred and fifty times.)

Canals isolated by hydrochloric acid, and coming from the carious dentine of man. These canals show various degrees of thickening; their contents are divided in the form of little bundles. In *a* a minute canal is seen greatly dilated, from which spring several undilated ramifications which are detached near their point of origin by the act of preparation. In *b* two small tubes very slightly dilated, one of which becomes gradually thicker.

FIG. 6. (Magnified two hundred times.)

Transverse section of a carious tooth, one made of hippopotamus ivory. A layer of *leptothrix* at the surface; similar masses penetrate (in *a*), proceeding from the surface, into the interior of the tissue (in *b*); they seem separate from the surface, because they have been crushed obliquely by the section. The dentinal canals are for the most part dilated (*c*); some of them still present the normal state (*d*).

FIG. 7. (Magnified two hundred and fifty times.)

Canals of the same tooth (hippopotamus) greatly dilated and presenting varicose sinuosities. At the right some of them are still united by very fine fibrils, which appear to be the residue of the dentine.

London, New Burlington Street.
February, 1878.

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